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AFTAC Project No. VT/9707

LONG PERIOD ARRAY PROCESSING DEVELOPMENT

Quarterly Report No. 5

1 May 1970 to 31 July 1970

T. W. Harley, Program Manager
Area Code 202, 244-4894

TEXAS INSTRUMENTS INCORPORATED
Services Group
P.O. Box 5621
Dallas, Texas 75222

Contract No. F33657-69-C-1063
Amount of Contract: $503,000
Beginning 21 April 1969
Ending 31 March 1971

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D.C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Order No. 624
ARPA Program Code No. 9F10

10 August 1970

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F33657-69-C-1063.

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I. INTRODUCTION AND SUMMARY

This fifth quarterly report describes progress made during the period 1 May 1970 to 31 July 1970 on the Long Period Array Processing Development program being conducted by Texas Instruments at the Seismic Array Analysis Center (SAAC). The purposes of the program are to develop on-line and off-line software to be used for evaluating the detection and discrimination capabilities of the Alaskan Long Period Array (ALPA), and to develop off-line software to be used for evaluating the detection and discrimination capabilities of stations of the Long Period Experiment.

The ALPA on-line package has been described previously in Quarterly Reports No. 1[1], 2[2], 3[3], and 4[4]. Routine operation of the on-line package has revealed several problems in the data preparation and quality check sections of the block processor. The remedial actions taken are discussed in Section II. These include the addition of a mean removal algorithm and modification of the quality check procedures.

During the 92 days of on-line operation covered by this report thirty-seven unscheduled program terminations have occurred; 20 due to machine or system problems, 6 due to operator or engineer errors, 1 due to program modification, 1 because the ALPA transmissions stopped for an extended period, and 9 due to other causes.

With the exception of the period 4 May to 11 May the polycode error rate has remained fairly stable at about 1 in 10^6 bits. A more serious difficulty has been the reception

of variable Julian dates with the data. This problem, which has persisted throughout the quarter, makes access of the data by the off-line programs difficult or impossible.

The off-line package was described previously in Quarterly Reports No. 1[1], 2[2], 3[3], and 4[4]. Section III discusses program MCFREP which has been added to the package during the fifth quarter. This program computes the frequency-wave-number response, the random noise response, and the infinite velocity response of multichannel filters. It also computes array response for specific site configurations.

Since 18 May the nine sites of ALPA included in radio links 0, 1, and 2 have been generally well recorded. Thus it has been possible to begin the evaluation phase of the program. To date two suites of events have been processed. The first of these contains nine events from the western United States; the second contains fourteen Sino-Soviet Events. Array processing was generally done with four to six sites. Matched filtering with a master waveform was fairly effective for the first nine events, but was not attempted for the Sino-Soviet events due to the lack of suitable master waveforms. The performance of chirp filters on the Sino-Soviet events was quite variable, being generally poor for epicenters in eastern Asia.

Much of the programming effort during the fifth quarter has been devoted to preparation of the Long Period Experiment software. A description of the programs is given in Section V along with status information. Tape formats are presented in Appendix A.

II. ON-LINE PACKAGE

A. Introduction

In previous quarterly reports, the basic design of the ALPA on-line package has been described. The initialization routine, control task, and the seven subtasks have all been discussed. In this report, problems within the quality check procedure, together with corrective steps either taken, being taken, or to be taken are discussed.

In addition, information about package operation, summary of down times, tape utilization, transmission statistics, and beam deployment, is reviewed in this section.

Finally, progress on the documentation of the ALPA on-line package is covered in the fourth subsection.

B. Package Configuration

During the fifth quarter, most of the changes in the ALPA on-line package occurred in the data preparation and quality check sections of the block processor. In the data preparation section, a mean-removal algorithm was implemented in order to reduce the effects of DC bias upon the channel power values used in the quality check section. In the quality check section, attempts were made to allow for the code associated with an event. These changes in the block processor will be discussed in the remainder of this subsection.

1. Mean Removal Algorithm

Most channels from ALPA have DC levels which generally are at least as large as the seismic data. Moreover, the DC levels vary as a function of time and can change substantially from day to day. Since the on-line quality check algorithm is based on channel power, it is essential that these large DC levels be removed prior to performing the quality checks. Consequently, the following on-line mean removal algorithm was implemented.

The algorithm consists of two parts:

- First, remove the mean from the data (channel by channel)

- Second, update the mean estimate (channel by channel)

In the first part of the algorithm the mean is removed from each channel point-by-point for 15 seconds of data:

$$X_i = X_i - M \qquad i = 1, 2, \ldots, 15$$

where M has been provided by initialization procedures or has been estimated from previous data.

$$\overline{X} = \frac{1}{15} \sum_{i=1}^{15} X_i$$

$$M^1 = \frac{(T-1)\ M + \overline{X}}{T}$$

Where M^1 is the new mean estimate, M is the old mean estimate, and T is the time constant (set to 20 blocks). if $M - \partial \leq M^1$

$\leq M + \partial$, the value M^1 is available for removing the mean from the next 15-second block. If $M^1 > M + \partial$ or $M^1 < M - \partial$, M^1 is replaced with the value $M^1 = M + \partial$ or $M^1 = M - \partial$. Here ∂ is the number of computer counts that the mean is allowed to vary over successive blocks (currently set to 2). This procedure is used to prevent spikes from biasing the mean.

Figures II-1a. through II-1h. show the data preparation section of the block processor as of 27 July 1970.

2. Modifications to Quality Check Algorithm

In July, it became apparent that the coda of an event was having adverse effects on the quality checks. First, the component long-term power averages were being biased upward by the power values occurring immediately after an event ended. This bias sometimes resulted in unrealistically high values for the component long-term power averages after several events had occurred. Second, channels still above tolerance after an event had ended were being thrown out by the quality checks (simply because they were slightly more powerful than the other channels).

Therefore, it was decided to allow for a coda period after an event. The coda period is defined to be an arbitrary period (specified in 15-second blocks) following an event declaration on any one of the three components. In addition, a component is declared to be in a "coda" state if another component is in an "event" state during the same 15-second block. During the coda period, all updating of the component long-term averages is suppressed. In addition, channels either above or within tolerance pass the seismic quality checks if the relevant component is in a "coda" state.

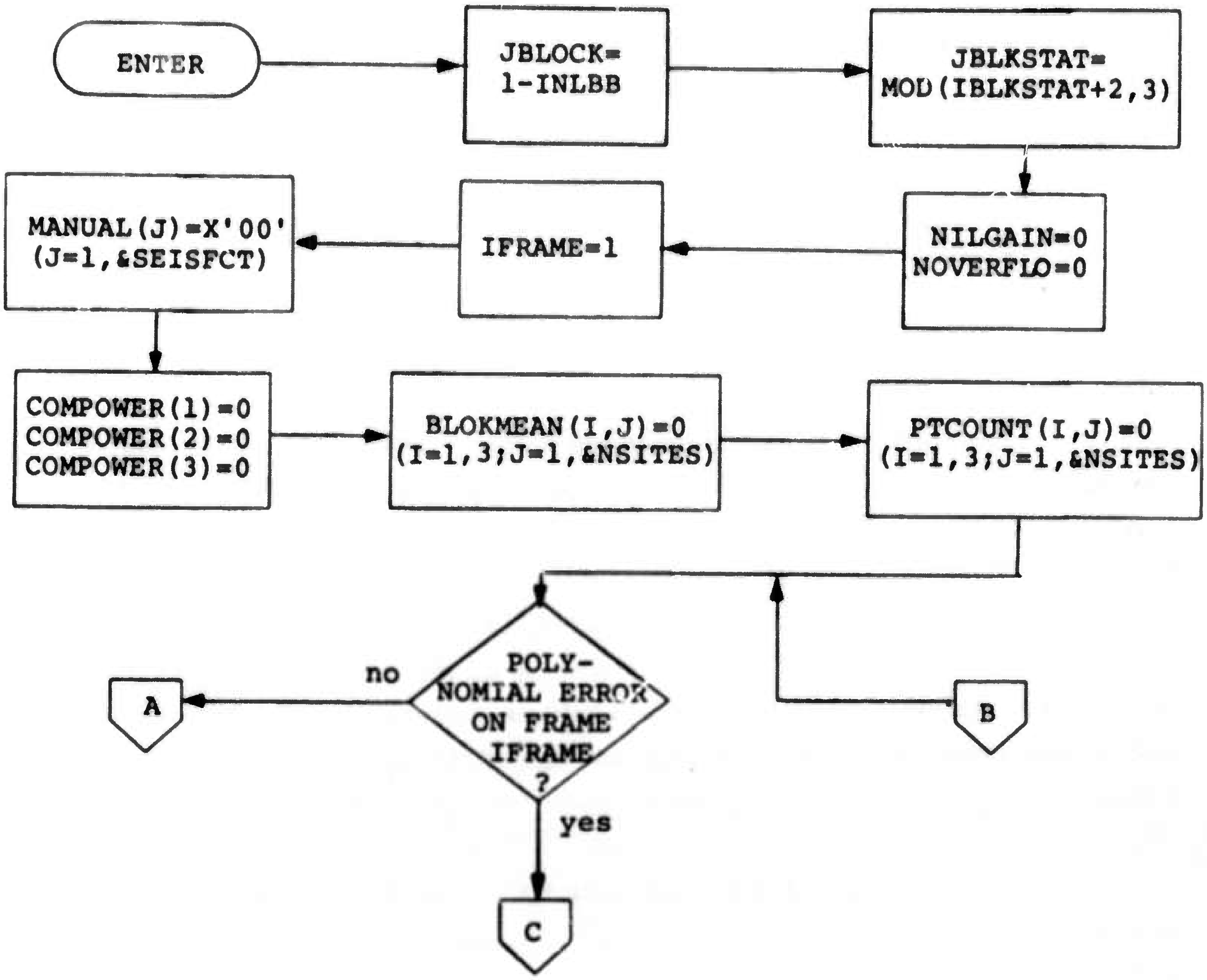


Figure II-1a.

BLOCK PROCESSOR
(DATA PREPARATION)

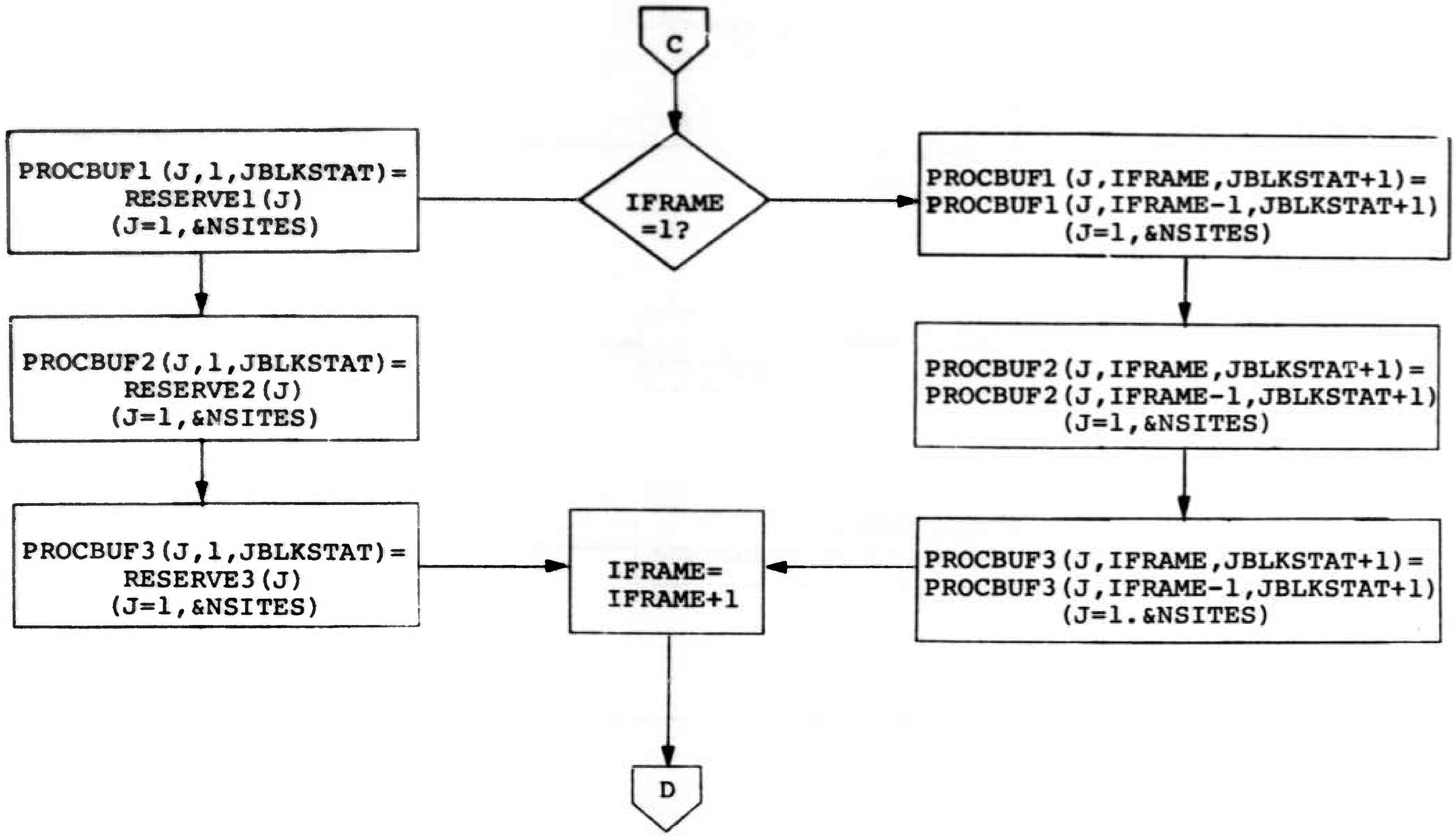


Figure II-1b.

BLOCK PROCESSOR
(DATA PREPARATION)

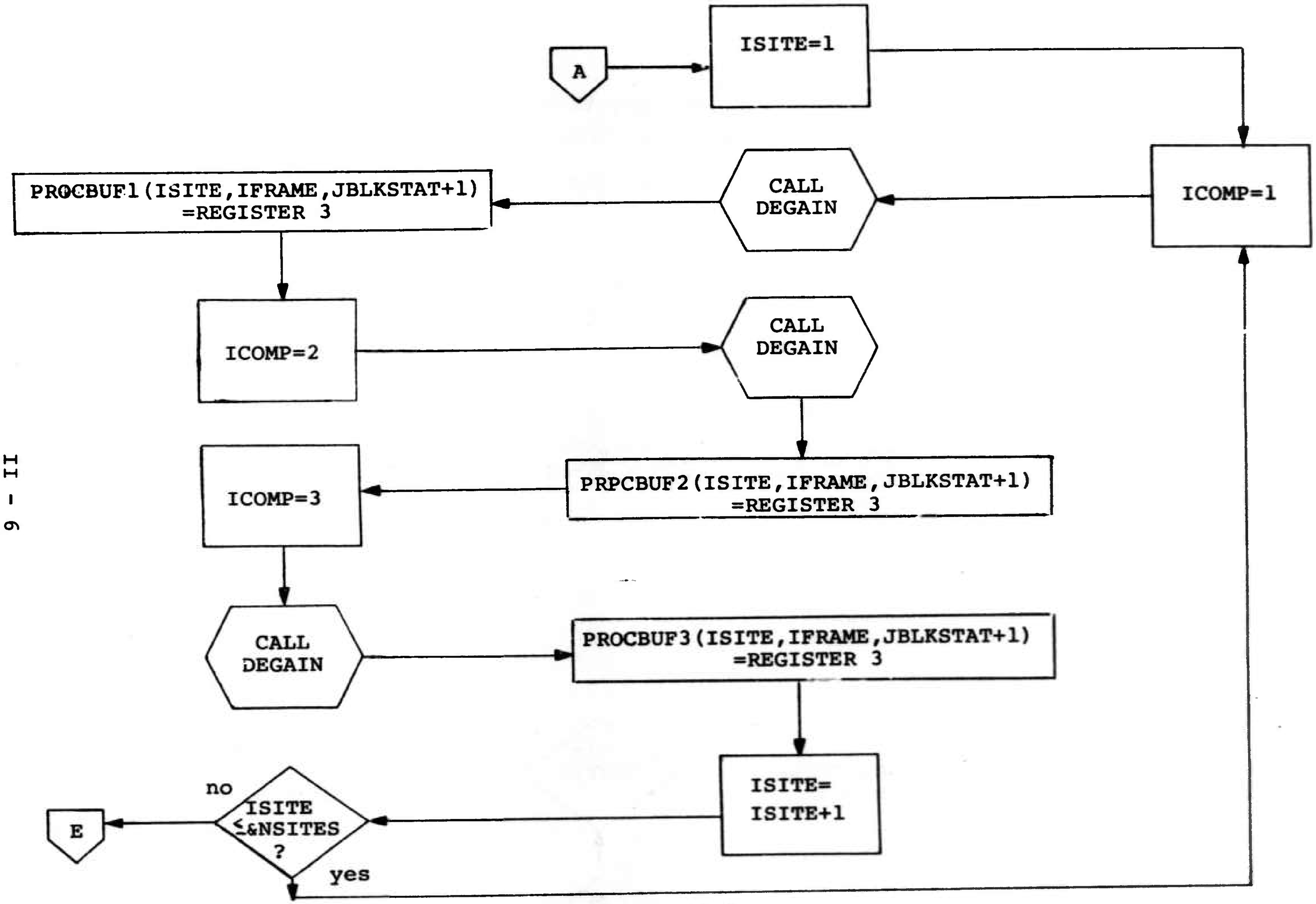


Figure II-1c.
BLOCK PROCESSOR
(DATA PREPARATION)

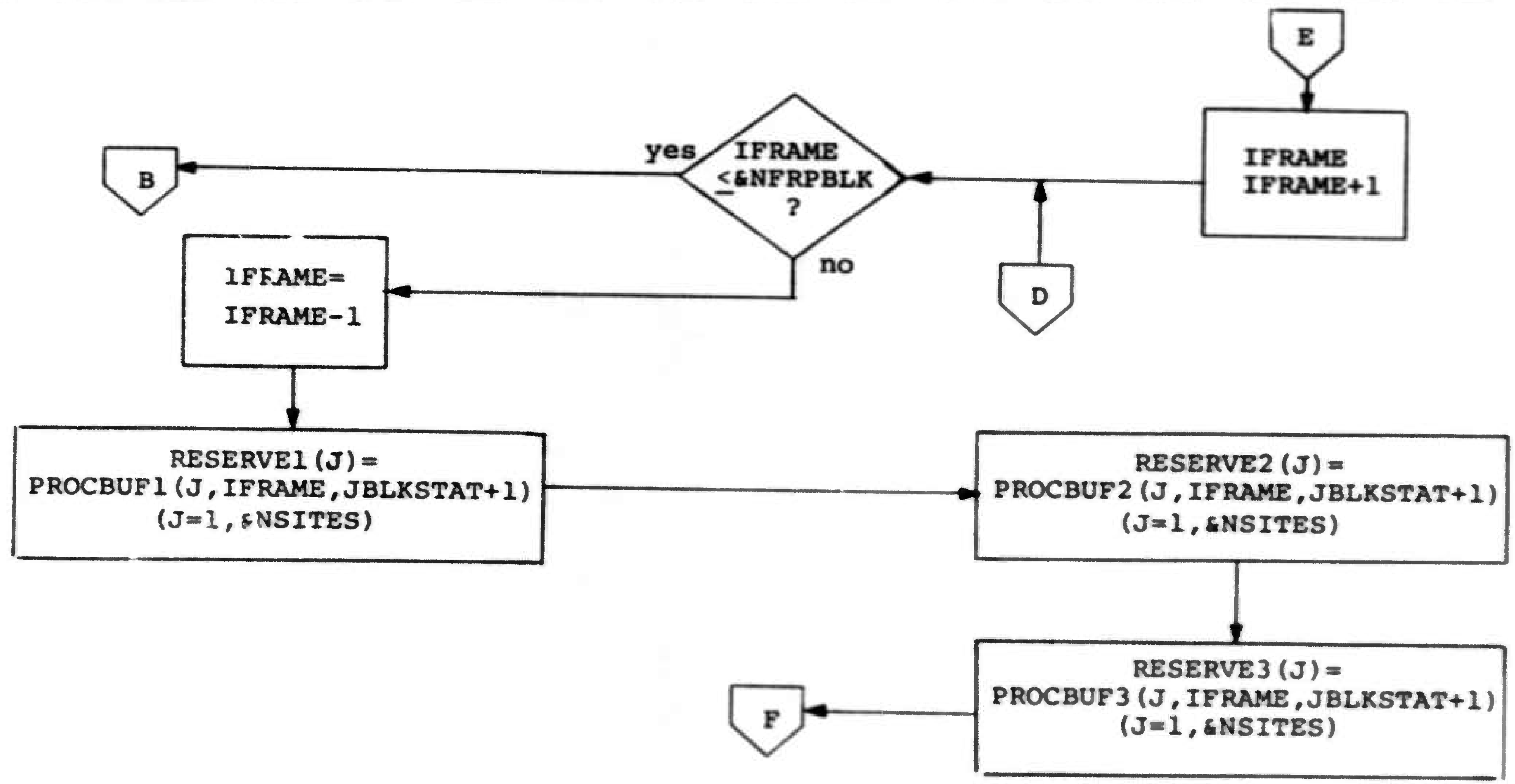


FIGURE II-1d.
BLOCK PROCESSOR
(DATA PREPARATION)

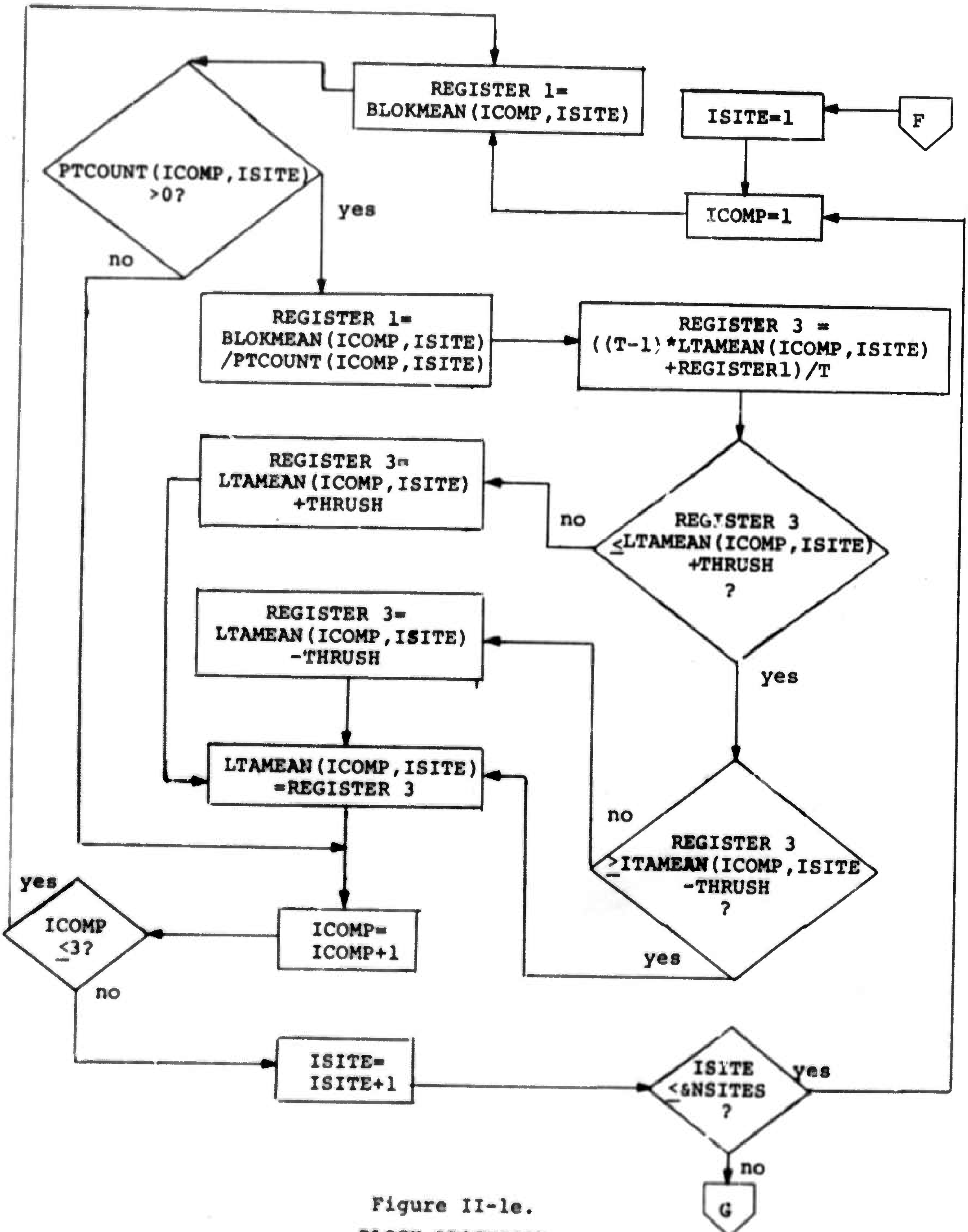


Figure II-1e.
BLOCK PROCESSOR
(DATA PREPARATION)

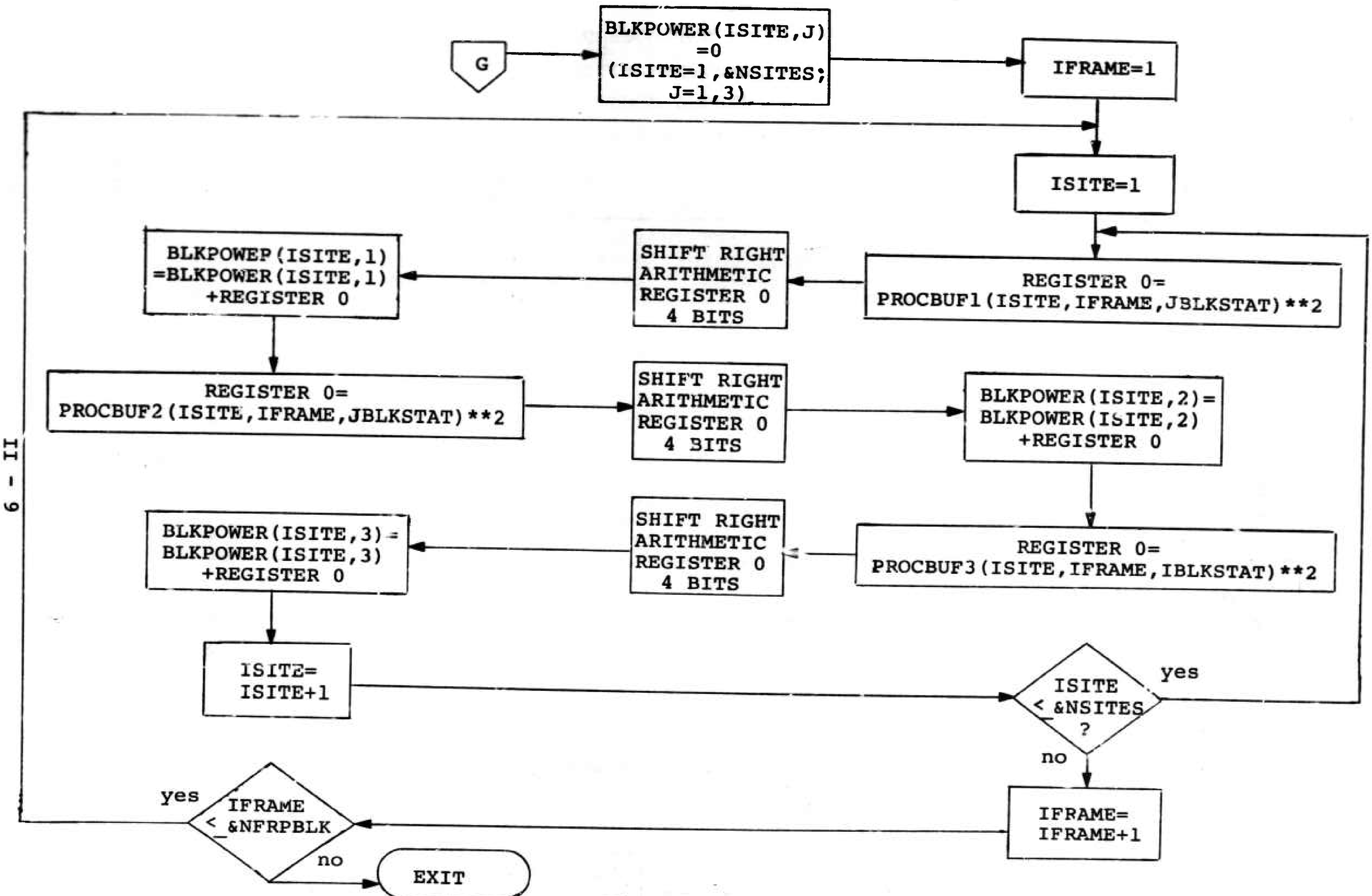


Figure II-1f.

BLOCK PROCESSOR
(DATA PREPARATION)
II - 9

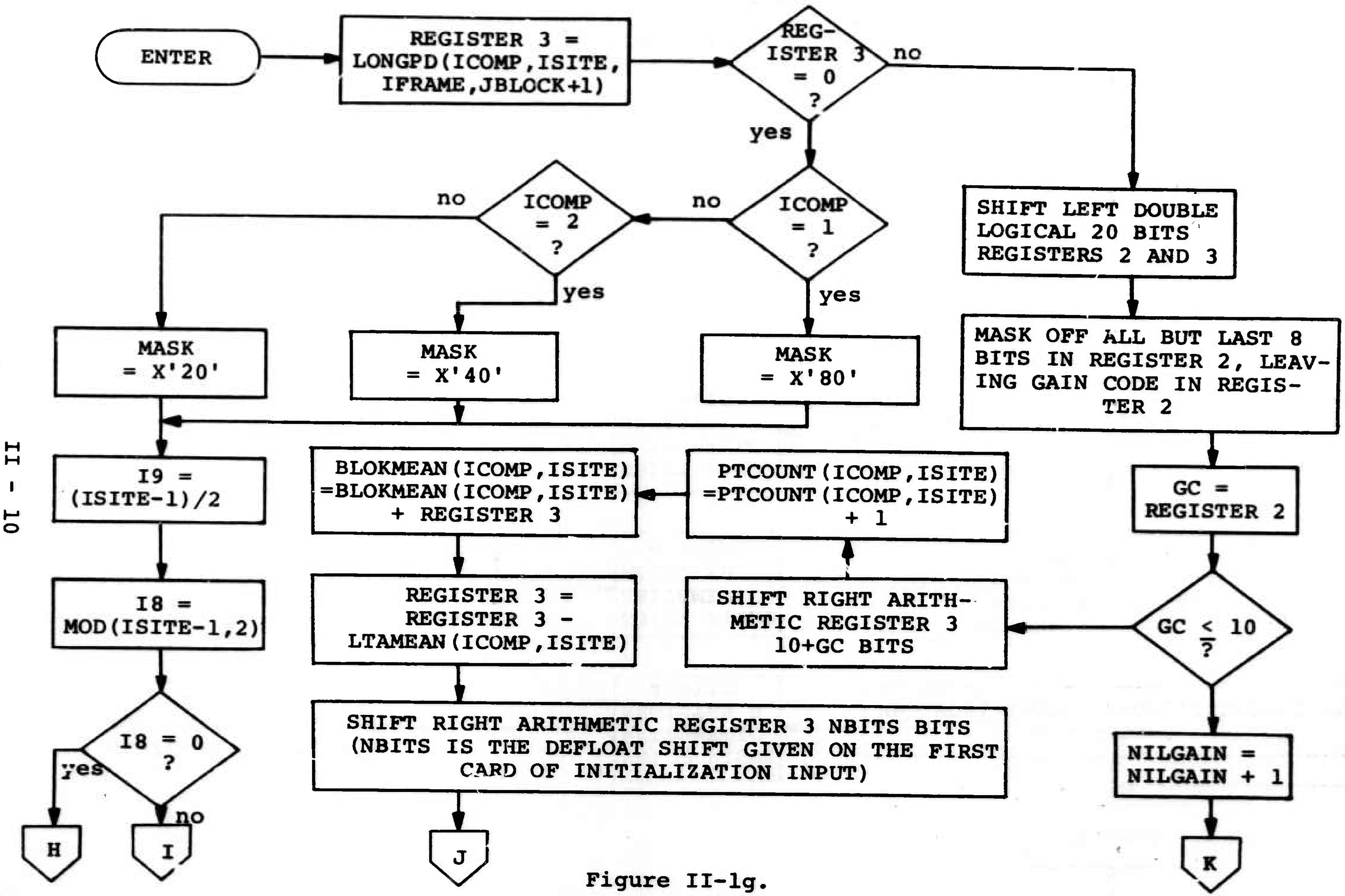


Figure II-1g.

BLOCK PROCESSOR

(DATA PREPARATION)

(SUBROUTINE DEGAIN)

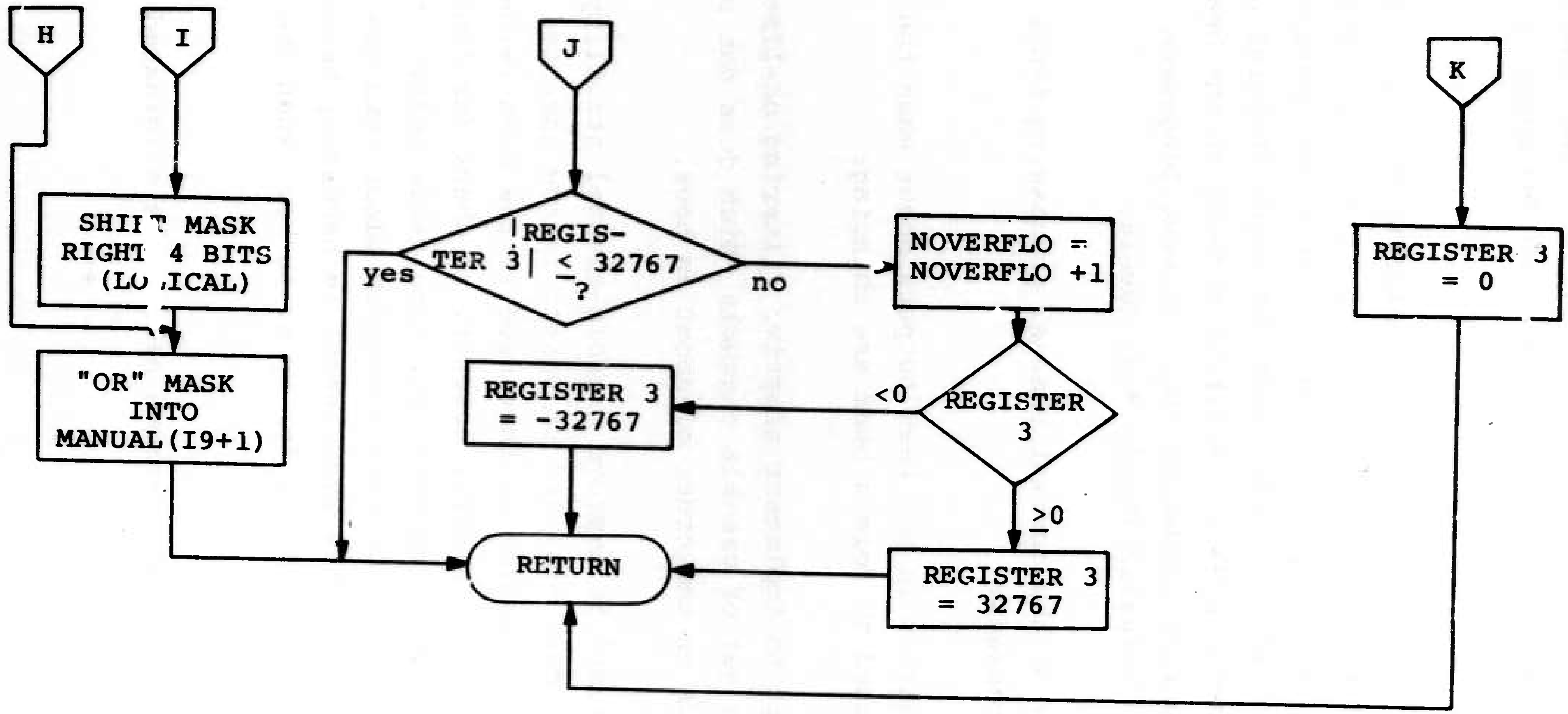


FIGURE II-1h.

BLOCK PROCESSOR
(DATA PREPARATION)
(SUBROUTINE DEGAIN)

Figures II-2, II-3a, II-3b, and II-4 reflect changes made in the quality check section of the block processor up to 28 July 1970.

With the quality checks implemented by 27 July, three problems still remained. First, the set of useable channels embodied in the current channel processing table was unstable over an hour-long period. Second, spurious event declaration often occurred, sometimes with disastrous effects on the beam outputs. Third, on rare occasions the component long-term averages climbed to unrealistically high levels.

Stability of the current channel processing table is important for two reasons:

1. Discontinuities in the beam outputs occur when the channels used to form a beam are changing;

2. Any attempt to implement adaptive filtering on-line requires a set of useable channels which does not change for periods on the order of about an hour.

In an attempt to improve useable-channel stability, the block power for each site and component is now computed using exponential smoothing similar to that used in the mean removal algorithm. It will be necessary, however, to check for flags in the site error table or seismometer function table before incorporating the power for the current 15-second block into the smoothed power average. This requirement is necessary because power from calibrations persists for up to an hour when the flags are not checked.

Spurious event declarations need to be eliminated

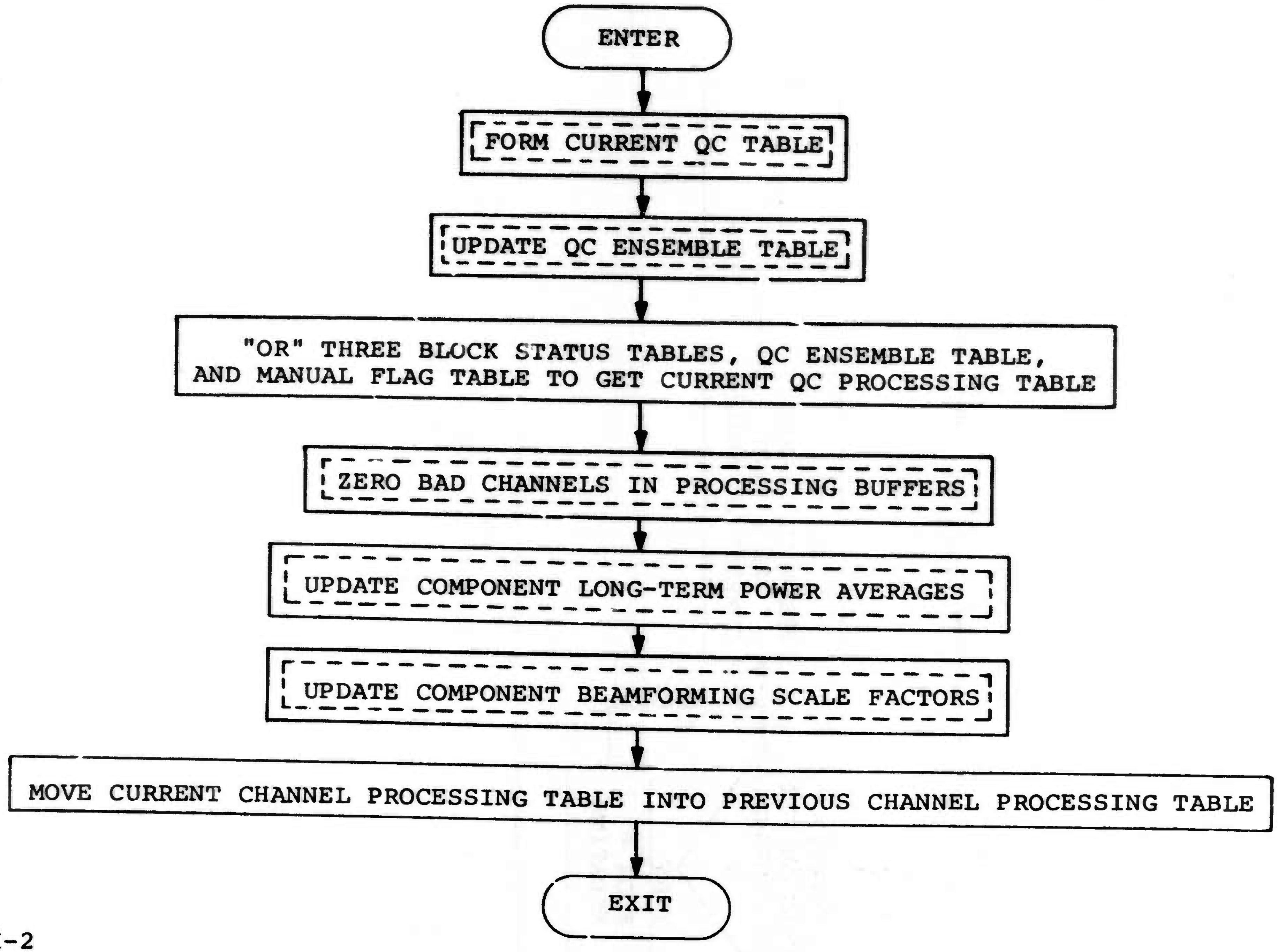


Figure II-2
BLOCK PROCESSOR

(QUALITY CHECK AND REMEDIAL ACTION)

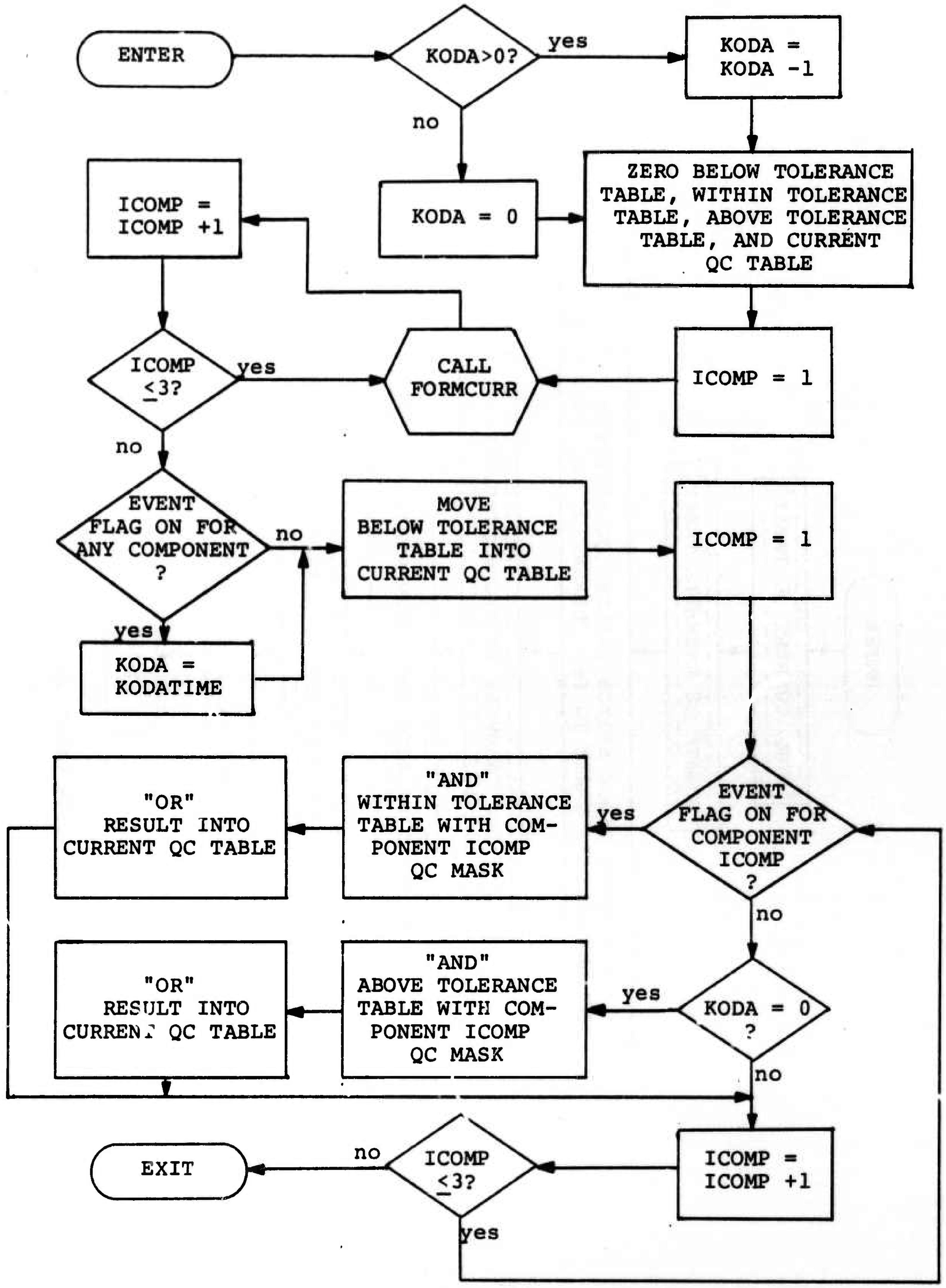


Figure II-3a. BLOCK PROCESSOR (QUALITY CHECK AND REMEDIAL ACTION) (FORM CURRENT QC TABLE)

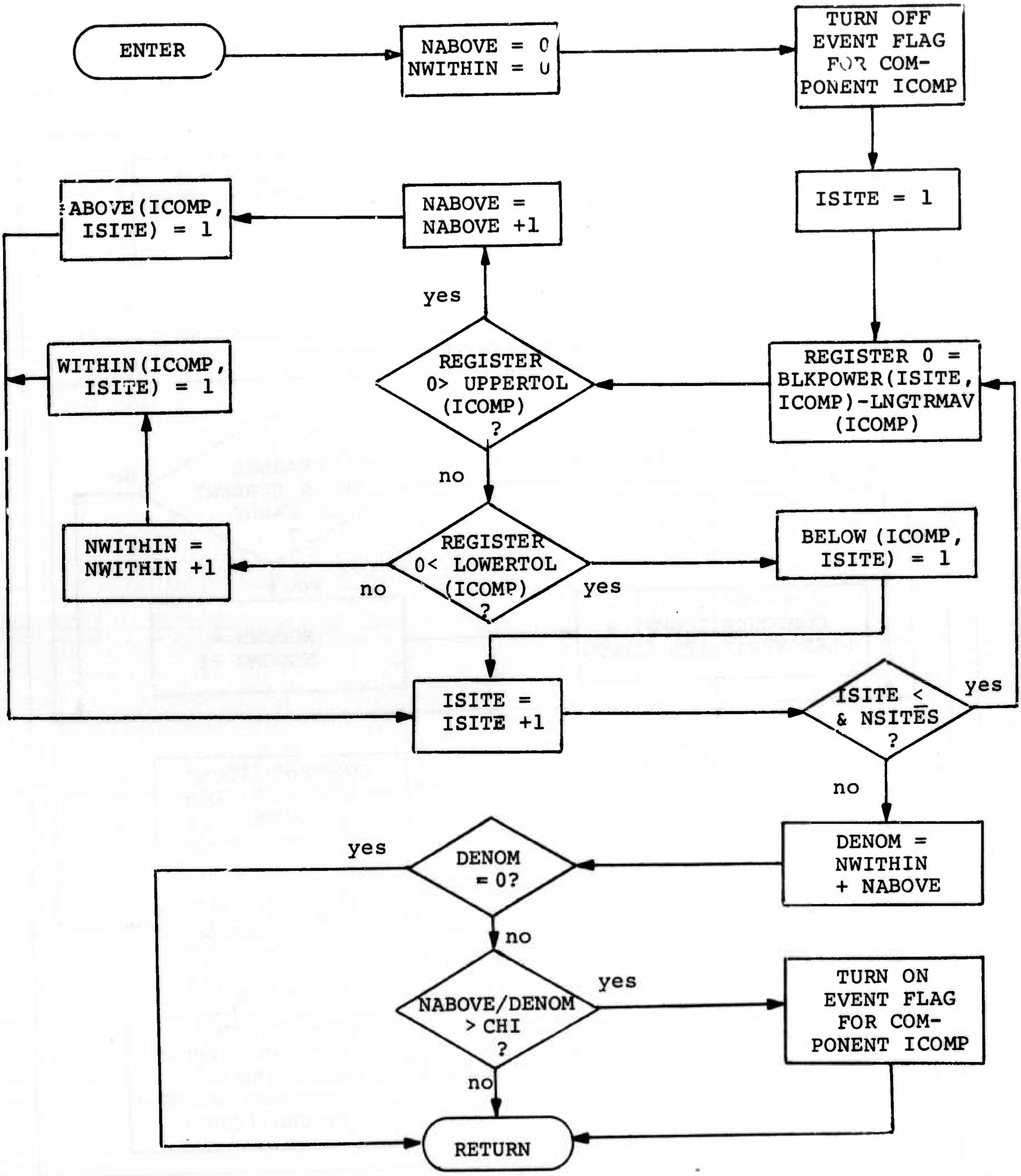


Figure II-3b. (QUALITY CHECK AND REMEDIAL ACTION)
BLOCK PROCESSOR (FORM CURRENT QC TABLE)
(SUBROUTINE FORMCURR)

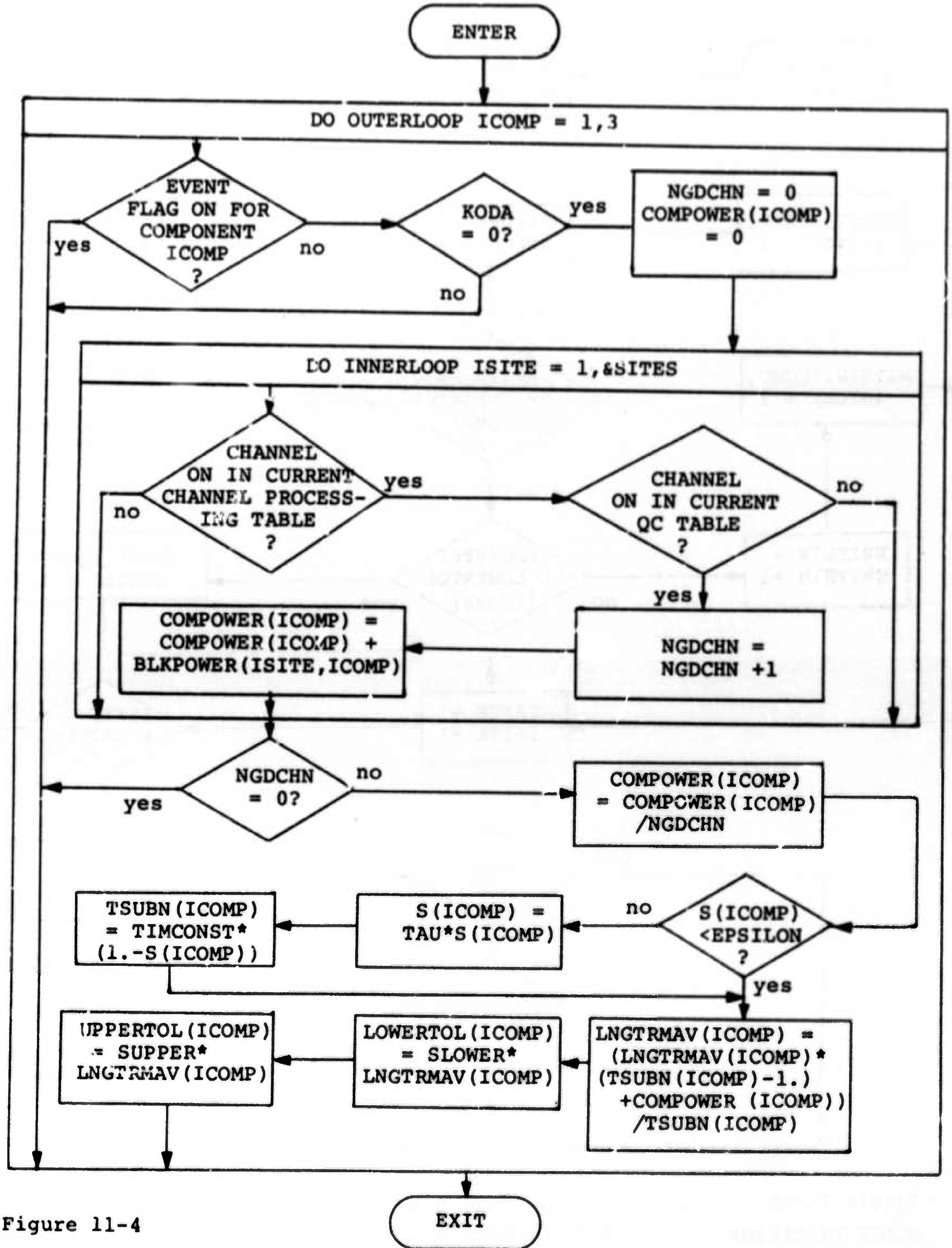


Figure 11-4
BLOCK PROCESSOR

(QUALITY CHECK AND REMEDIAL ACTION)
(UPDATE COMPONENT LONG-TERM AVERAGES)

because, in combination with a noisy channel, they can cause alternating sequences of normal beam outputs followed by noisy beam outputs (due to the noisy channel).

These spurious event declarations appear to be caused by (1) fluctuations in the channel power values, (2) the present order in which the quality checks are performed, and (3) a possibly too low event trigger factor.

The exponential smoothing of the channel power values tends to diminish the effects of the fluctuation. In an attempt to make it harder for events to be declared, the event trigger factor has been increased from 0.50 to 0.74. It is still necessary to change the order so that the quality checks are performed after the point at which the site error table, seismometer function table, and manual flag table are incorporated into the current channel processing table. This should reduce the instances of event declarations when there are noisy channels or values other than '0000' have been transmitted in the positions reserved for sites 10-19, and is presently being incorporated.

On relatively infrequent occasions, the component long-term averages have climbed to unrealistically high levels. This problem causes the quality check algorithm to think that the channels with reasonable power levels are dead. For this reason, upper and lower limits for the component long-term power averages have been set.

C. Package Operation

1. Summary of Down Times

TABLE II-1

ABNORMAL TERMINATIONS OF ON-LINE PACKAGE

(5/1/70 to 7/31/70)

CAUSE	NUMBER OF OCCURRENCES
MACHINE CHECK OR MALFUNCTION (Hardware Problems)	13
SYSTEM PROBLEM	7
OPERATOR ERROR	3
ENGINEER ERROR	3
PROGRAM MODIFICATION	1
ALPA TRANSMISSIONS STOPPED	1
OTHER	9
TOTAL	37

During the 3-month period 1 May to 31 July, there were 37 abnormal terminations of the ALPA on-line package. Table II-1 summarizes the reasons for termination.

As in the 77 days ending on 30 April 1970, the most frequent cause for termination was a machine check. There were 13 such machine checks in the most recent 3-month period as compared with 14 during the first 77 days.

System problems were the second most frequent cause for termination. There were 7 terminations for this reason as compared with 3 during the earlier period. These problems are generally beyond the control of anyone at SAAC. IBM corporate system programmers were called in to investigate some of the system failures and bugs were found in DOS Release 20. Remedies may be forthcoming in later releases of DOS.

Operator errors remained at a low level, engineer errors decreased to a low level.

One programming error had to be corrected on 18 June. The error was introduced 16 June.

The ALPA on-line package was taken down once due to extended absence of transmissions from Alaska as compared with 9 times in the earlier 77-day period. There were two principal reasons:

1. Transmission gaps were less frequent and;

2. The on-line package was not taken down until 12 midnight (Washington time) as long as Geotech personnel were present at the ALPA MMC.

The most frequent problem in the "other" category was that ALPA was switched from one computer to another. Such switchovers occurred 5 times. These switchovers occur when IBM decides it must have the 40B machine for such purposes as transatlantic link tests or parallel runs where the IISPS and ISRSPS systems are run together. One termination was necessitated by removal of the 40X for shipment to Norway. Another occurred when a defective disk drive part was replaced before the normal preventative maintenance period. Another occurred in order to permit diagnostics to be run on the ALPA 2701 when excessive polycode errors were detected. Telephone company employees apparently caused another termination when they were working on the phone line used to transmit to the VSC develocorder.

2. Tape Utilization

As of 10 August, data are being written on tape 148 of the 200 tapes allocated for on-line processing. At a projected usage rate of one tape per day, the existing stock of library tapes should be used up around the end of September.

3. Transmission Statistics

Starting on 4 May, polycode errors were detected with every transmission. After extensive investigations at the ALPA MMC and at SAAC and after several line checks on the telephone line from Alaska to SAAC, the trouble was found in the ALPA 2701 to SAAC. It was corrected on 11 May by an adjustment to the ALPA 2701. After that period, the polycode rate has generally been fairly stable at approximately 1 in 10^6 bits (3 errors per hour).

More serious problems have been encountered with ALPA

timing word. The ALPA timing word is the only means available by which a given frame of data can be associated with the time the data frame was sampled. During early May, a minor problem occurred in switching from one minute to the next. The minute code was not incremented until the second code reached 01 after the minute code was supposed to have changed. The result was the sequence;

X minutes 59 seconds

X minutes 0 seconds

X+1 minutes 1 second

This problem was corrected during May. A major problem has persisted during the entire quarter from May through July: the Julian date has often changed every few hours. The problem is apparently in the time code interface at the MMC. The result is that off-line processing is severly handicapped in its efforts to identify and to access data for a given event when the Julian date is wrong anywhere on the tape containing the data.

4. Beam Deployment

On 10 August, upon verbal request from AFTAC, the beams were redeployed as described in Table II-2 .

D. Documentation

Documentation of the ALPA on-line package neared completion during the fifth quarter. Rough drafts of Section I (Introduction), Section II (Functional Description), Section IV

TABLE II-2a

DEPLOYMENT OF BEAMS

(10 August 1970)

BEAM NUMBER	VELOCITY (km/sec)	AZIMUTH
1	3.75	0°
2	3.75	60°
3	3.75	120°
4	3.75	180°
5	3.75	240°
6	3.75	300°
7	3.75	330°
8	7.0	300°
9	7.0	360°
10	∞	-

TABLE II-2b

VSC DEVELOCORDER

TRACE NUMBER	DESCRIPTION	COMPONENT	SHIFT
A1	Beam 1	VERTICAL	0
A2	BEAM 2	VERTICAL	0
A3	BEAM 3	VERTICAL	0
A4	BEAM 4	VERTICAL	0
A5	BEAM 5	VERTICAL	0
A6	BEAM 6	VERTICAL	0
A7	BEAM 8	TRANSVERSE	0
A8	BEAM 9	TRANSVERSE	0
B1	BEAM 10	VERTICAL	0
B2	BEAM 8	RADIAL	0
B3	BEAM 5	TRANSVERSE	0
B4	BEAM 6	TRANSVERSE	0
B5	BEAM 1	TRANSVERSE	0
B6	SITE 5	VERTICAL	2
B7	SITE 5	NORTH	2
B8	SITE 5	EAST	2

CONTINUED

TABLE II-2c

SAAC DEVELOCORDER

TRACE NUMBER	DESCRIPTION	COMPONENT	SHIFT
A1	SITE 1	TRIAX 1	3
A2	SITE 2	TRIAX 1	3
A3	SITE 3	TRIAX 1	3
A4	SITE 4	TRIAX 1	3
A5	SITE 5	TRIAX 1	3
A6	SITE 6	TRIAX 1	3
A7	SITE 7	TRIAX 1	3
A8	SITE 8	TRIAX 1	3
A9	SITE 9	TRIAX 1	3
B1	BEAM 1	VERTICAL	2
B2	BEAM 1	TRANSVERSE	2
B3	BEAM 2	VERTICAL	2
B4	BEAM 3	VERTICAL	2
B5	BEAM 3	VERTICAL	2
B6	BEAM 5	VERTICAL	2
B7	BEAM 6	VERTICAL	2
B8	BEAM 7	VERTICAL	2
B9	BEAM 7	TRANSVERSE	2

Site numbers refer to the order in which sites are transmitted from ALPA. Shifts given represent the power of two by which the traces are scaled down.

(Operating Considerations), and Section V (Input/Output) were completed during July. In addition, detailed flowcharts of the entire on-line package as it stood July 27 were completed The two major aspects of the documentation yet to be completed are descriptions of the task functions and a definition of variables and constants used in the coding.

Documentation requirements for the on-line package are expected to be satisfied during September.

III. OFF-LINE PACKAGE

A. Introduction

In the four previous quarterly reports the basic design of the off-line software was outlined and discussed.[1-4] Also, the signal edit and enhancement packages and the analysis and utility programs were described. These programs and packages were checked out during the first four quarters of the contract using three events.

B. Package Configuration

As more channels at the ALPA site became operational during the fifth quarter, data analysis was changed from a debug mode to a production mode. In this production mode, it was possible to test all of the various program options and interfaces. These checks showed several areas in the main packages which could be modified to facilitate their use and effectiveness. The majority of these modifications were involved with tape I/O error recovery routines. Others were involved with data annotation differences between program packages which were not apparent during program debug due to the channel configuration of the software test data.

As mentioned, some program changes were performed to increase program operating efficiency. An example of this type of program change was the addition of a master wave form input tape to the program BEAMAN.[4] This change allows the data analyst to store a large number of event master wave forms on a data tape instead of eighty column data cards. Program execution time will not be greatly affected by this change

since a trade-off will be encountered between searching the master waveform tape for the correct event and reading the master waveform cards. However, the analyst will not have to maintain a large file of data cards and thus the chance of error will be greatly reduced.

One new program was added to the off-line package during the past quarter. This program computes filter and array responses and is described in Section III-B-1.

1. MCFREP

This program provides a means for evaluating the performace of both multichannel filters and beamsteer processors using a given site configuration. Evaluation of MCF's includes:

- Response to random noise
- Response to infinite velocity energy
- V-$\vec{k}$ wavenumber response

The array response for any given site configuration of up to twenty-two sites may be determined and a letter plot of $\vec{K}$ space provided.

Random noise response (R) of a set of complex filter coefficients (FIL) at a given frequency is defined to be:

$$R = \sum_{I=1}^{NSITES} (FIL(I) \times FIL(I)^*)$$

where * indicates complex conjugate.

The random noise response is calculated at each frequency for which filter coefficients have been determined and a printer plot of response vs. frequency in db is provided.

The response to infinite velocity energy (IV) is calculated as:

$$IV = \left(\sum_{I=1}^{NSITES} FIL(I)\right) \times \left(\sum_{I=1}^{NSITES} FIL(I)\right)^{*}$$

The same type of display is provided as for the random noise response.

Conventional wavenumber spectra of each MCF set may be calculated for selected frequencies. Let the frequency domain filter at frequency (f) on channel j be $H_j(f)$. The filter set for all channels then defines a filter vector $\left\{H(f)\right\}$. The scanning vector $\left\{V_{\vec{k}}\right\}$ is defined as usual:

$$V_{\vec{k}} = \begin{Bmatrix} e^{-i2\pi\vec{x}_1 \cdot \vec{k}} \\ \cdot \\ \cdot \\ \cdot \\ e^{-i2\pi\vec{x}_n \cdot \vec{k}} \end{Bmatrix}$$

The response ($P_{\vec{k}}$) at wavenumber $\vec{k}$ is then:

$$P_{\vec{k}} = \left\{V_{\vec{k}}\right\}^{*T} \left\{H(f)\right\}^{*} \left\{H(f)\right\}^{T} \left\{V_{\vec{k}}\right\}$$

If we define $A_{\vec{k}}$ as follows:

$$A_{\vec{k}} = \left\{H(f)\right\}^{T} \left\{V_{\vec{k}}\right\}$$

then we can compute $P_{\vec{k}}$ as:

$$P_{\vec{k}} = \left| A_{\vec{k}}^{*} \right| \left| A_{\vec{k}} \right|$$

This routine is also used in calculating the array response by setting the filter coefficients for each site in the array to the value 1/N. Output is a printer plot of response level as a function of $\vec{k}$ space location at a given frequency.

A general flowchart of MCFREP is given in Figure III-1 As can be seen from the chart, input to the program may be from tape or cards. Each previously described type of evaluation is optional with the exception that in order to do infinite velocity or random noise response plots, input must be from tape. In calculating wavenumber plots, the flow of the program is as shown in Figures III-2 through III-5.

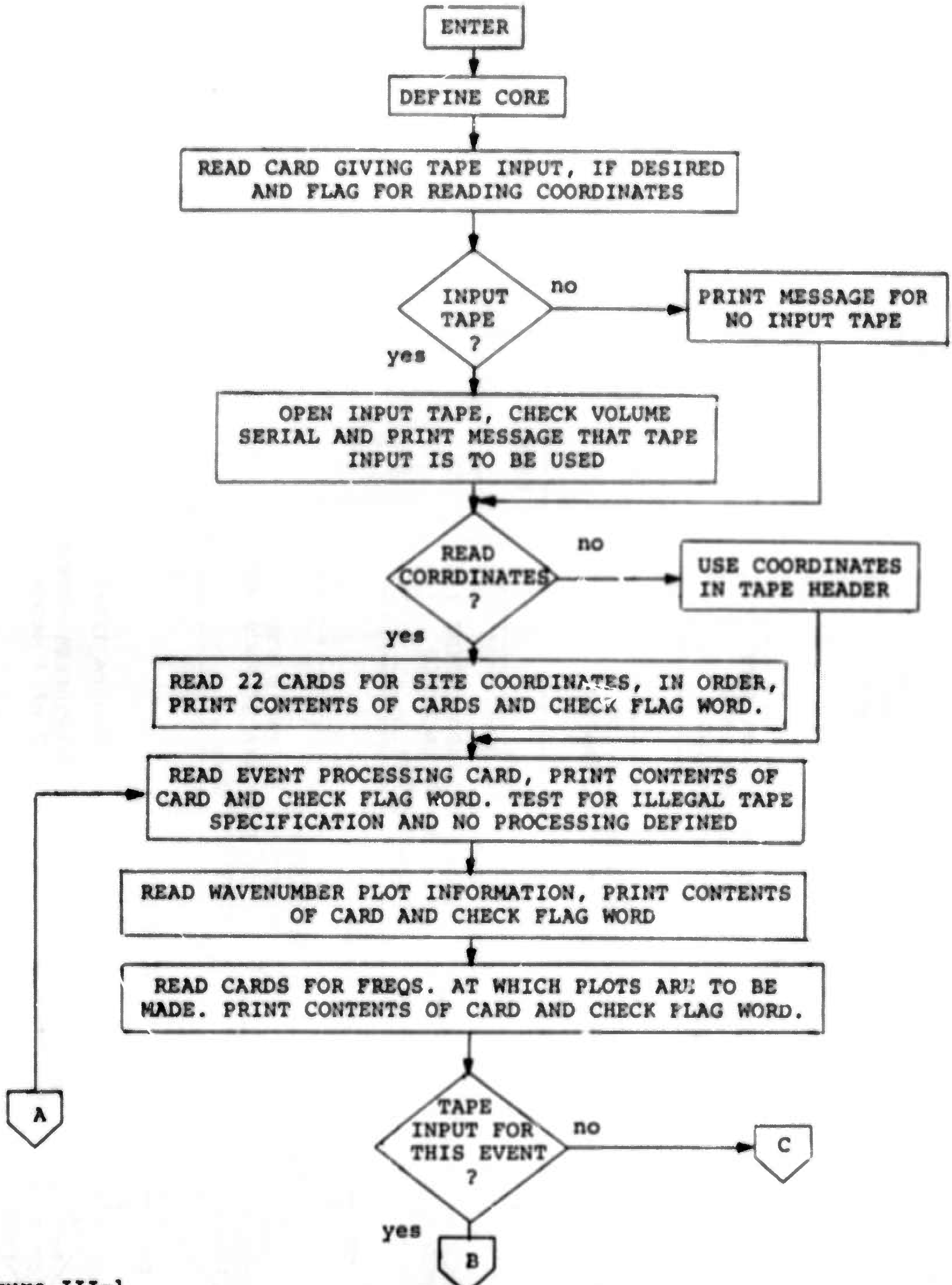


Figure III-1

SUBROUTINE MCFREP
1 of 3 pages

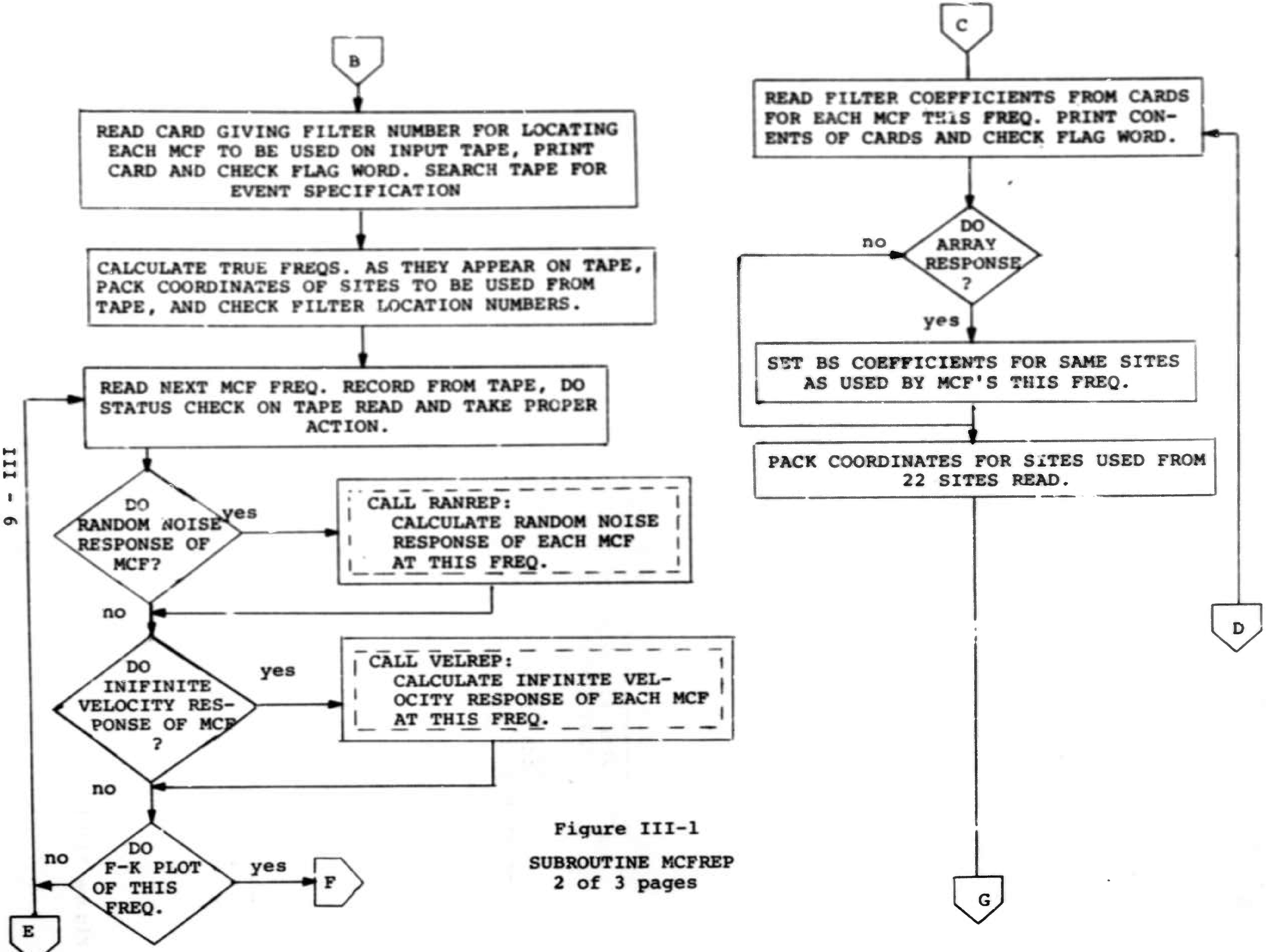


Figure III-1

SUBROUTINE MCFREP
2 of 3 pages

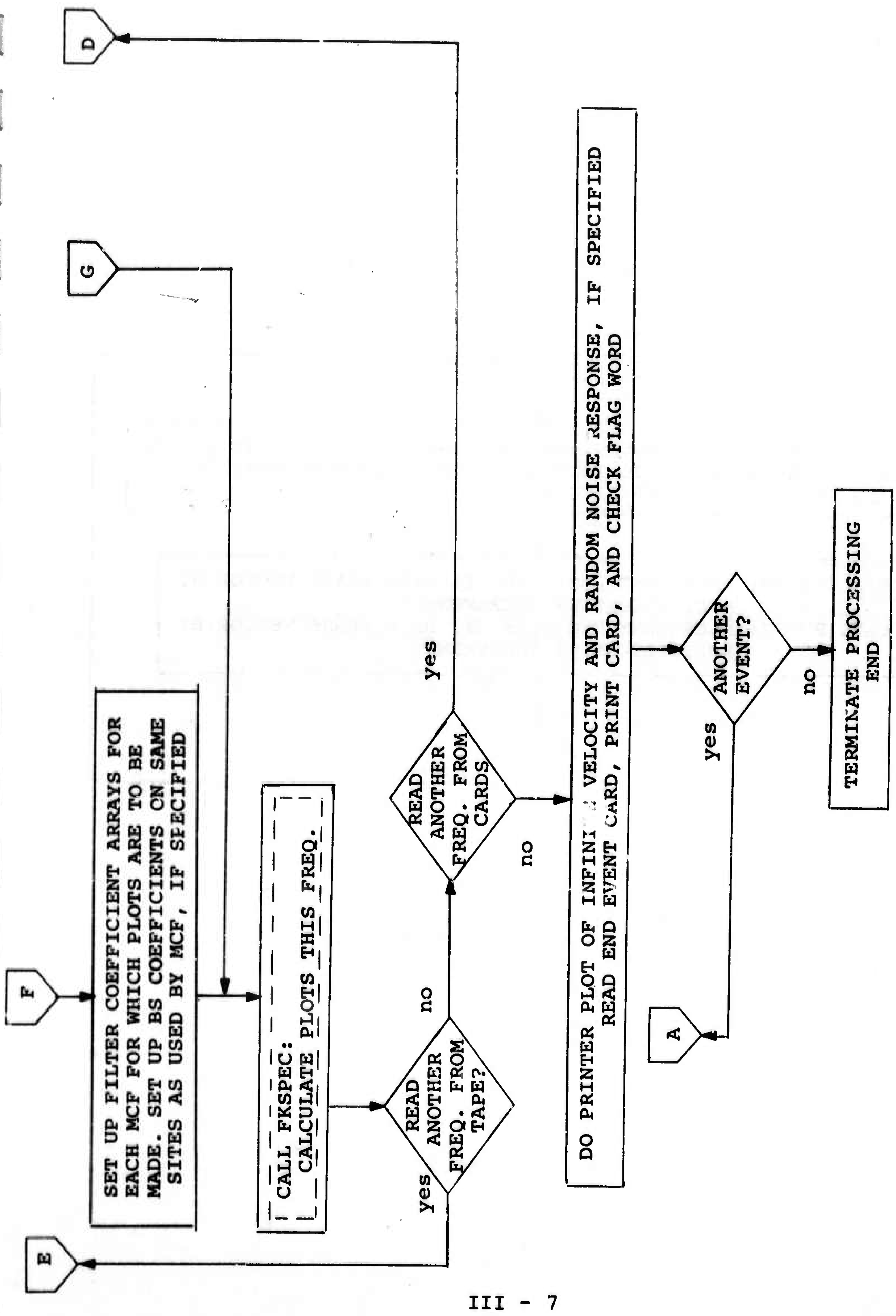


Figure III-1
SUBROUTINE MCFREP
3 of 3 pages

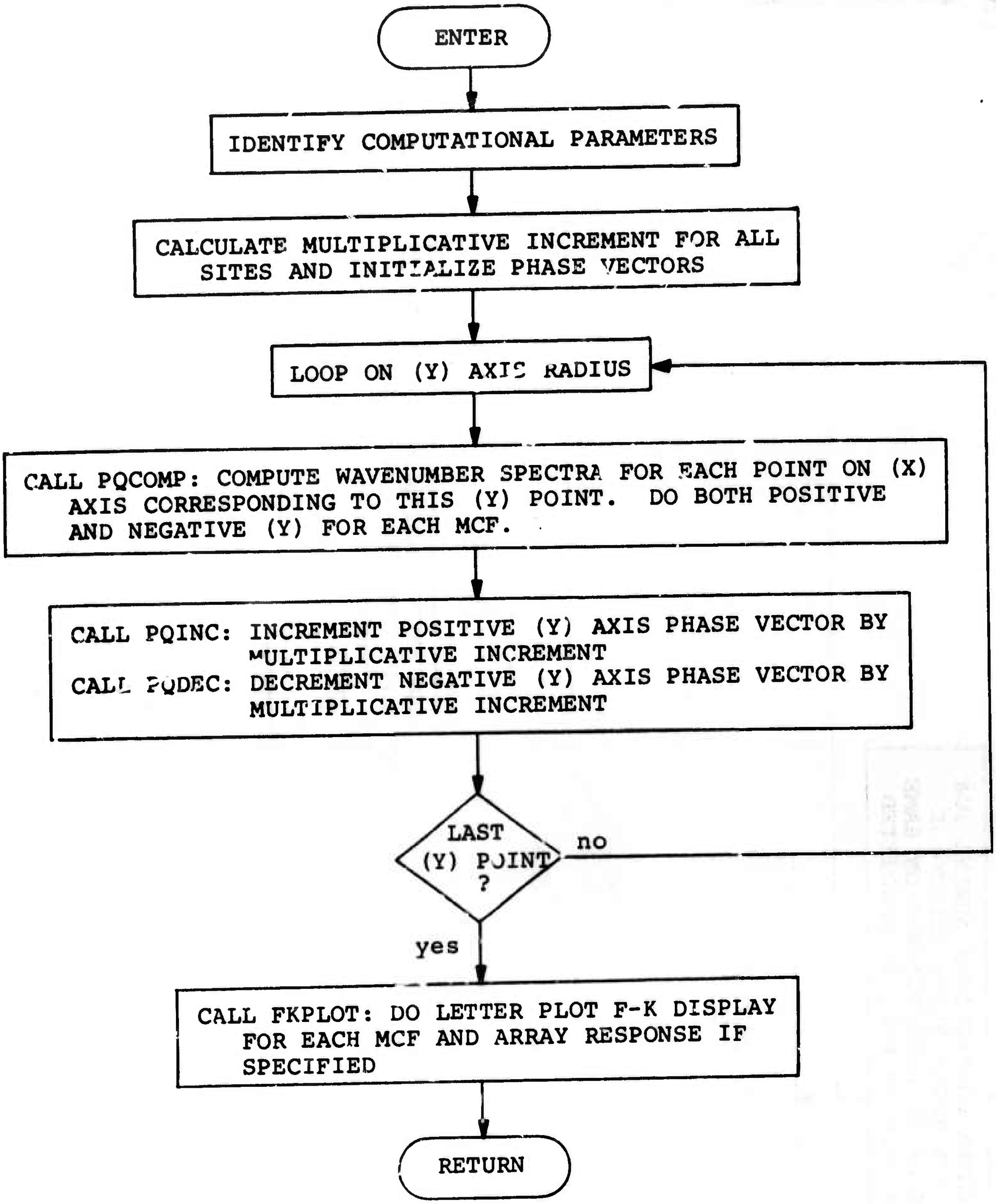


Figure III-2

SUBROUTINE FKSDEC

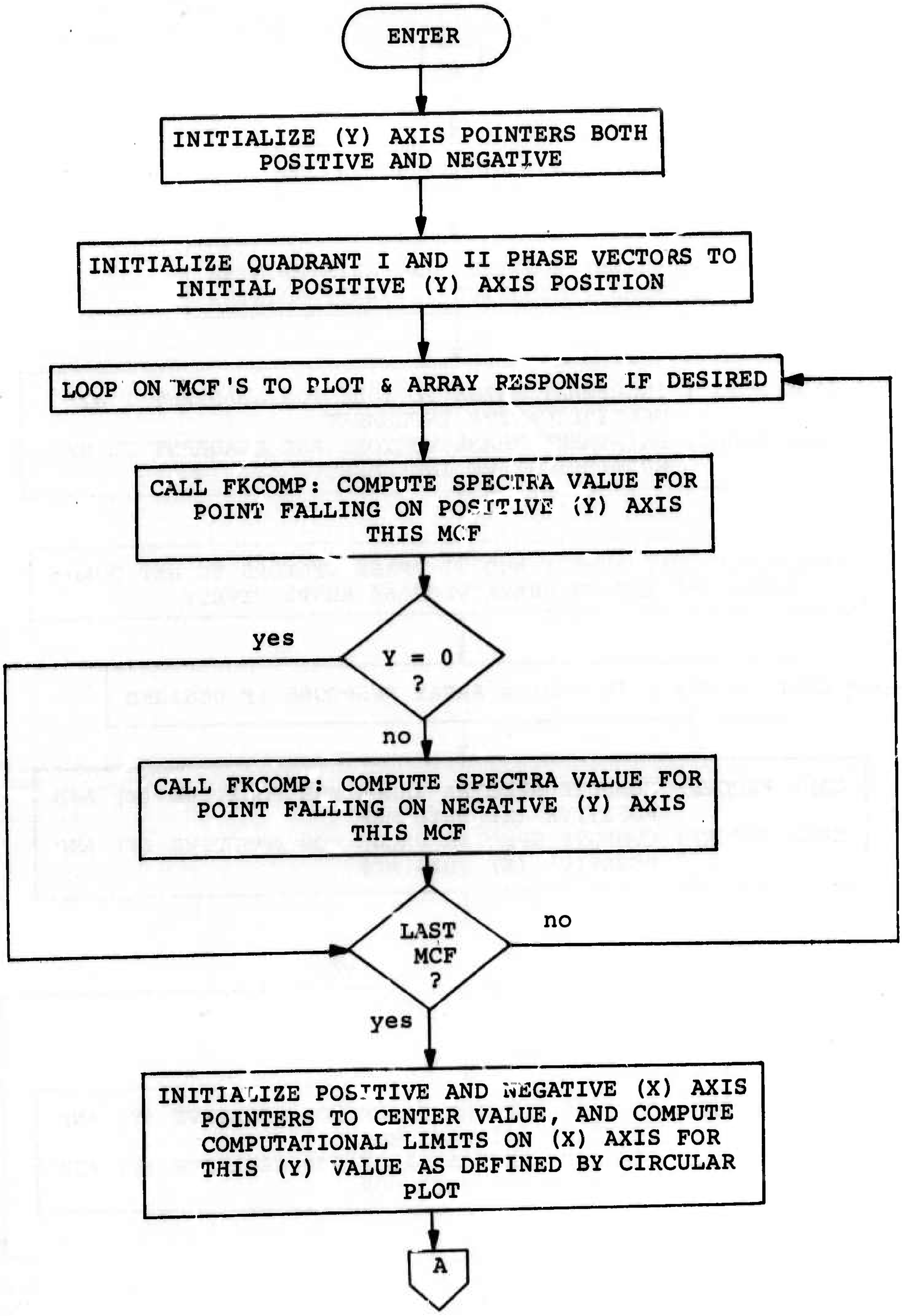


Figure III-3

SUBROUTINE PQCOMP
1 of 3 pages

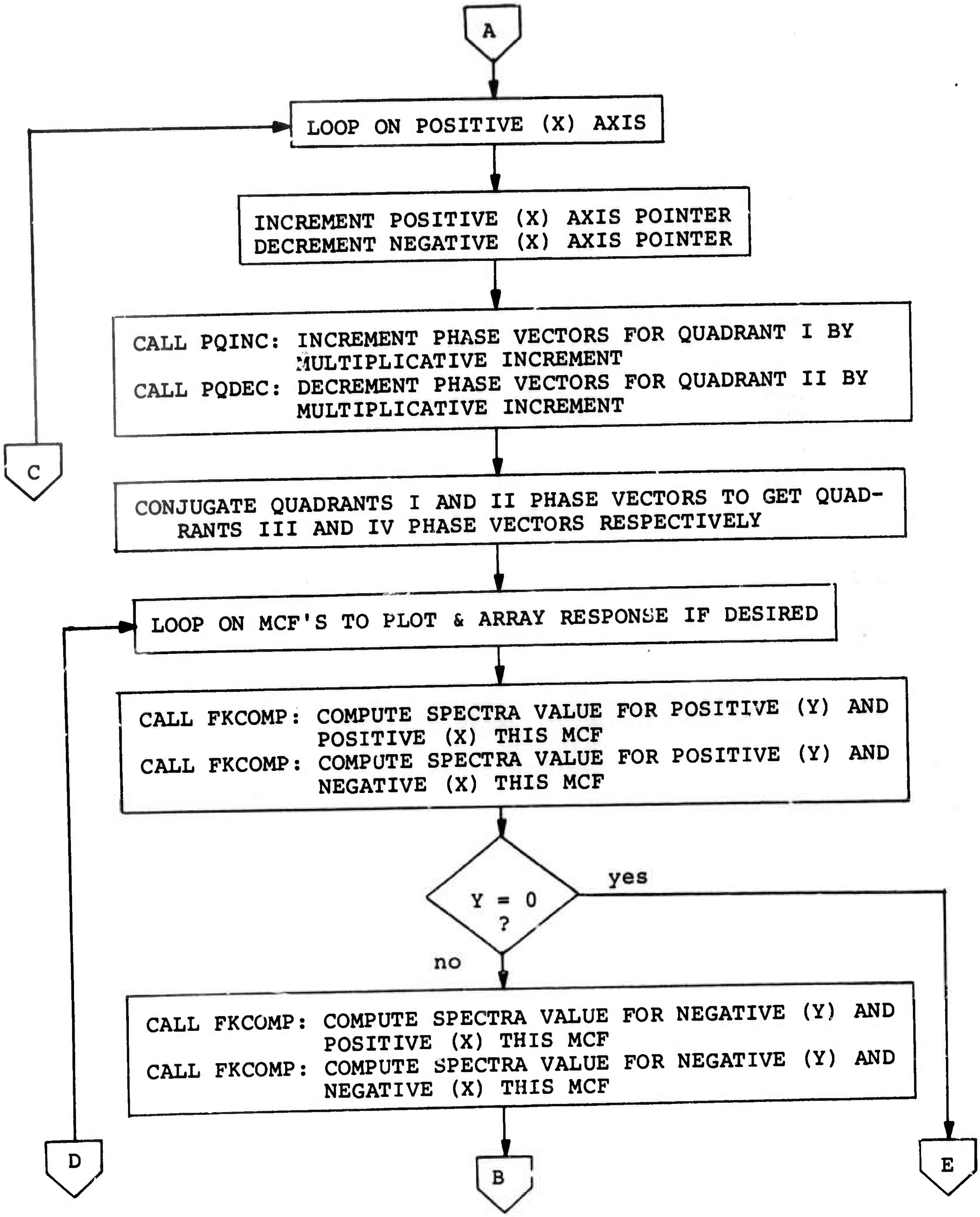


Figure III-3

SUBROUTINE PQCOMP

2 of 3 pages

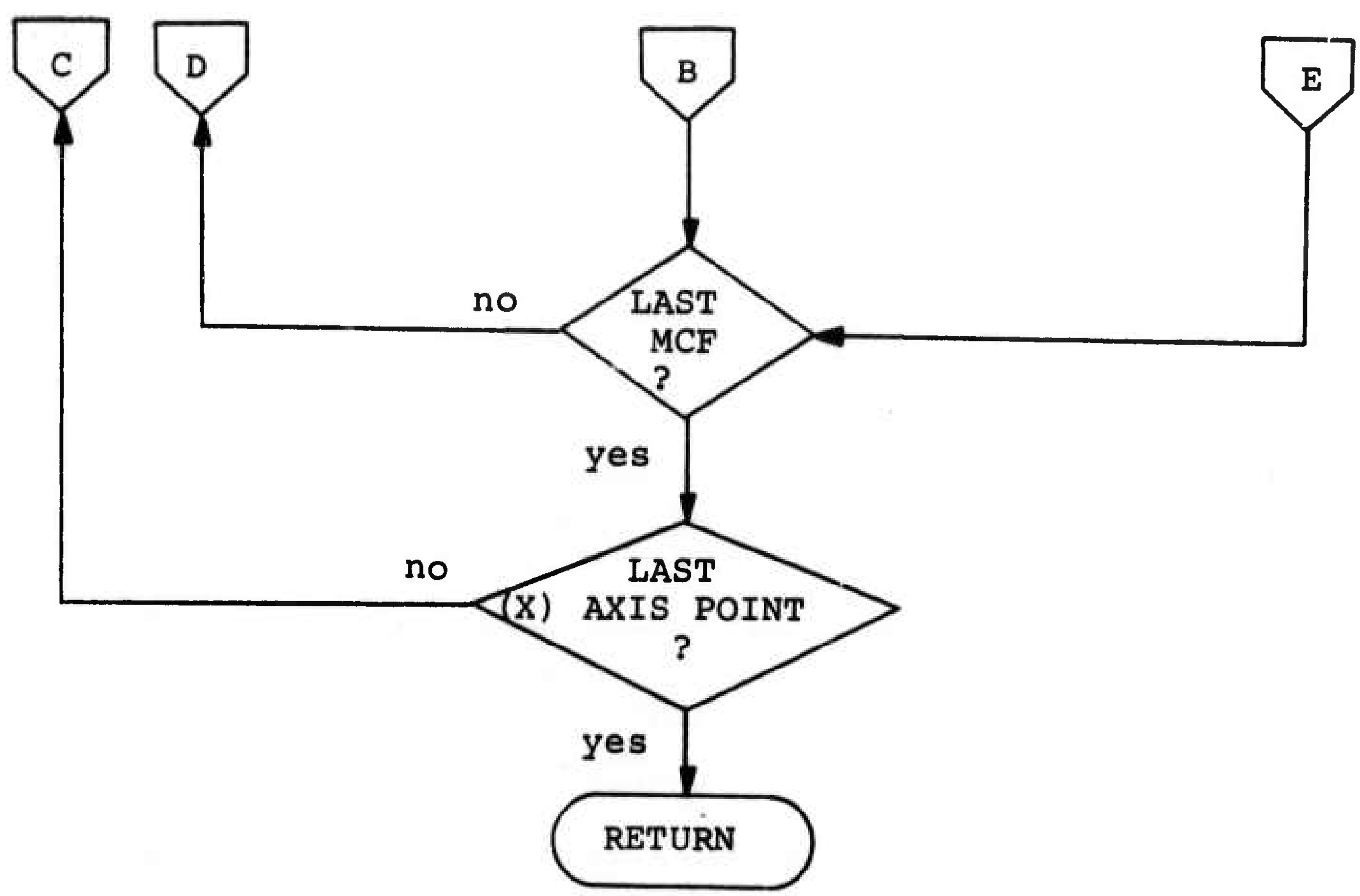


Figure III-3

SUBROUTINE PQCOMP
3 of 3 pages

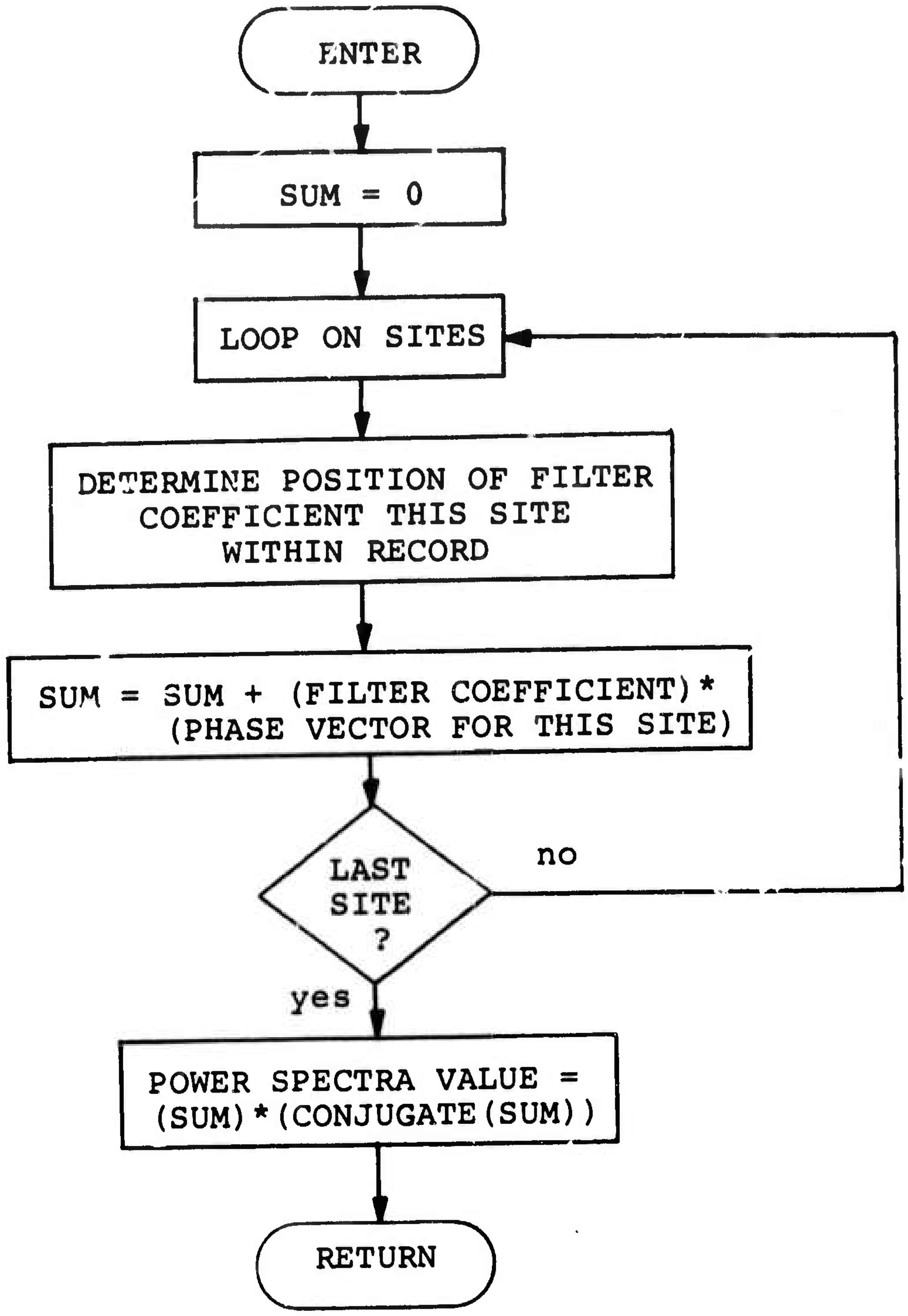


Figure III-4
SUBROUTINE FKCOMP

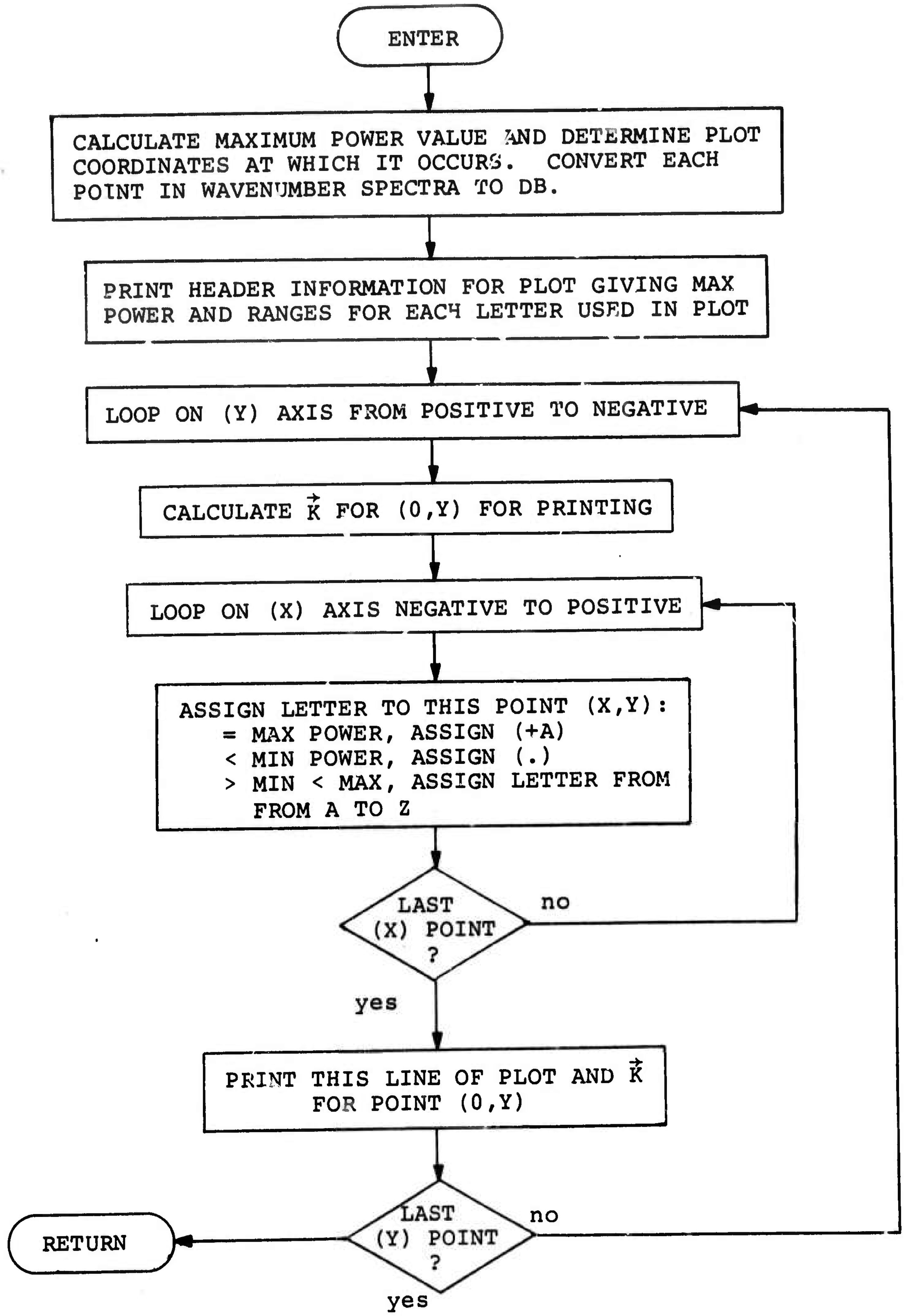


Figure III-5

SUBROUTINE FKPLOT

IV. ALPA EVALUATION

A. Introduction

The nine sites of ALPA in radio links 0, 1, and 2 have been installed and operational for several months. Prior to mid-May various problems precluded effective array processing of the data. Since 18 May the quality of the data has significantly improved, and it has been possible to begin the evaluation in earnest.

Two suites of events have been processed. The first consists of nine events from the western United States. The second consists of fourteen Sino-Soviet events. Results of this processing are discussed below.

Several anomalous conditions have been noted. Two of the triax components at site 1-1 and one component at site 2-2 originally had polarities opposite to those at the other sites. All components at site 1-1 had a high system noise level. Both of these conditions have now been corrected. The high-level long-period noise observed during the winter months of 1969-70 has largely subsided. It is still noticeable at several sites, most prominently at site 3-34 and to a lesser degree at sites 1-1 and 2-2.

A significant difficulty in off-line processing arises as a result of anomalous timing codes transmitted to SAAC with the data. These times are placed on the library tapes with the data and are used to locate the data by the off-line programs. When

an anomaly occurs, it frequently makes the associated data inaccessible on the library cape.

B. Array Processing

Each of the events in the two suites mentioned above have been array processed using either a multichannel filter or a beamsteer or both. Some initial comparison of the two approaches has been made, but the conclusions are too tentative. to merit reporting at this time.

Analysis of noise data recorded prior to each of the events indicates that the microseismic peaks typically contain energy propagating from the south with surface-wave velocities. Multiple coherence estimates obtained with five to eight sites typically range from 0.85 to 0.93 in the range 16-18 seconds.

Multiple coherence here and in the future on this program will be defined in terms of the following partitioned crosspower matrix:

$$\begin{bmatrix} \Phi 11 & \Omega 12 \\ \Omega 21 & \Omega 22 \end{bmatrix}$$

where:

$\Phi 11$ is the autopower of the reference trace,

$\Omega 12$ is the row vector of crosspowers $\Phi 12$ through $\Phi 1N$

$\Omega 21$ is the conjugate transpose of $\Omega 12$,

$\Omega 22$ is the crosspower matrix formed by channels 2 through N.

Multiple coherence is defined as:

$$\frac{\Omega 12 \quad \Omega 22^{-1} \quad \Omega 21}{\Phi 11}$$

Examination of the events recorded to date indicates that they are quite well equalized across the nine-element array and that signal degradation by the array processors is not significant. Based on past experience, this is the expected result.

C. Matched Filtering Studies

Each of the events in the two suites has been matched filtered, either with a master waveform or with a chirp waveform. In the case of large events this was done to examine the SNR gains obtainable with matched filters, and to calibrate the outputs. In the case of small events this was done in an effort to extract the events.

Chirp filtering is accomplished by specifying and applying the filter in the frequency domain following the technique used at Lincoln Laboratory. The chirp response function is:

$$G(f) = e^{i2\Pi(C/N)\,(k-ko)^2}, \text{ if } k_L \leq k \leq k_H$$

$$= 0 \qquad , 0 \leq k < k_L \text{ and } k_H < k \leq \frac{N}{2}$$

$$G(-k) = G(k)^*$$

where:

k is the discrete Fourier transform frequency index,

k_L and k_H correspond to the lowest and highest frequencies in the passband,

ko is the frequency index at which zero phase shift occurs,

N is the number of transform points,

C is a parameter which controls the length of the corresponding time-domain waveform.

This specification leads to a dispersive time-domain waveform with a linear group delay.

The SNR improvement of the matched filter is the ratio of the change in the peak value of the signal to the change in the rms value of the noise effected by the filter. Performance of the filter is judged in comparison with the performance of a zero phase bandpass filter having the same passband. For either the chirp or the master waveform case it is not expected that the phases of the matched filter will relate to the phases of the seismic noise in the passband in a consistent manner. Thus the matched filter effect on the rms value of the noise should be the same as that of the corresponding bandpass filter; both simply eliminate those frequency components outside the passband. This is true provided that the matched filter and bandpass filters have the same amplitude response, as is the case for the chirp specification above.

Master waveform filters are also applied in the frequency domain. Their response functions are obtained by

conjugating the Fourier transform of the time-domain master waveform, zeroing the coefficients outside the desired passband, and scaling the transform to make the largest modulus in the passband equal to 2.0. Since the amplitude spectrum of the event is generally not flat in the passband, the scaling is done to make the average amplitude spectrum across the passband approximately one. Roughly speaking then the master waveform filter should affect the rms value of the noise is about the same way as the corresponding bandpass filter.

Several noise samples have been processed with chirp and master waveform matched filters, and with the corresponding zero-phase bandpass filters. In each case the rms value of the noise after processing with the three filters did indeed prove to be essentially equivalent. Thus a simple and valid measure of matched filter performance is the ratio of the peak value of the matched filtered signal to the peak value of the bandpass filtered signal.

Table IV-1 lists the suite of the nine events from the Western United States, giving USC&GS magnitudes. Those events designated NTS have been identified by USC&GS as having occurred at the Nevada Test Site. One of these, NTS03 or "Handley," had large well defined surface waves. Its surface waves were used as the master waveform for matched filtering the other events. The improvements obtained when Handley was matched against itself and against two other NTS events are given in Table IV-2. These are the ratio of the peak in the matched filtered output to the peak in the bandpass filtered output. The filtering was done over two passbands, 0.02 to 0.075 hz and 0.025 to 0.05 hz. For the Rayleigh wave, the use of Handley on the two other NTS events yielded results slightly

TABLE IV-1

WESTERN UNITED STATES EVENTS

DATE	ORIGIN TIME	DELTA	AZIMUTH	m_b	DESIGNATION
26 MARCH	19:00:00.0	33.3	130.9	6.5	NTS03
21 MAY	14:00:00.4	33.4	130.9	3.5	NTS04
21 MAY	14:15:00.0	33.0	131.1	5.1	NTS05
23 MAY	22:55:22.4	34.1	125.5	4.6	S003
23 MAY	08:55:09.4	34.7	114.7	4.1	S002
24 MAY	02:09:53.4	34.0	125.6	-	S004
26 MAY	14:16:00.2	33.4	131.4	5.0	NTS01
26 MAY	15:00:00.0	33.4	131.4	5.6	NTS02
7 JUNE	04:12:10.3	27.4	142.1	5.0	S005

inferior to the match of Handley against itself. For the Love wave, Handley proved to be a poor matched filter, particularly for NTS05. This is consistent with the observed waveform for the Love wave of NTS05, which was quite different from that of Handley. This difference is probably related to differences in the mechanism for generating Love waves for the NTS events.

Line 2 of Table IV-2 shows the improvement achieved with a chirp filter operating on Handley. A suite of five chirps with varying lengths was used, the middle one having the expected surface wave length for NTS events at ALPA. The increment in length between the chirps was 50 seconds, and the chirp yeilding the largest peak output was chosen as the best match. The chirp filter proved to be inferior to the master waveform filter for this particular travel path. This is not surprising since the Handley Rayleigh wave shows significant interference at ALPA (Quarterly Report No. 4)[4].

Figure IV-1 is a plot of USC&GS m_b verses ALPA M_s for the six events of this suite which were detected. M_s for the four larger events were obtained directly from the bandpass vertical component beam. The two smaller events were not detected in the bandpassed beam, but were detected by using Handley as a master waveform matched filter. The conversion from matched filter peak output to M_s was obtained by comparing the matched filtered outputs for NTS02 and NTS05 with their surface wave magnitudes. Event S003 was located about 4° from NTS and it is possible that a good match was not obtained in this case. If so M_s estimate is probably low.

Table IV-3 lists the suite of fourteen Sino-Soviet events. These events were scattered over a large area, and no

FIGURE IV-1

M_s VS m_b FOR WESTERN USA

EVENTS

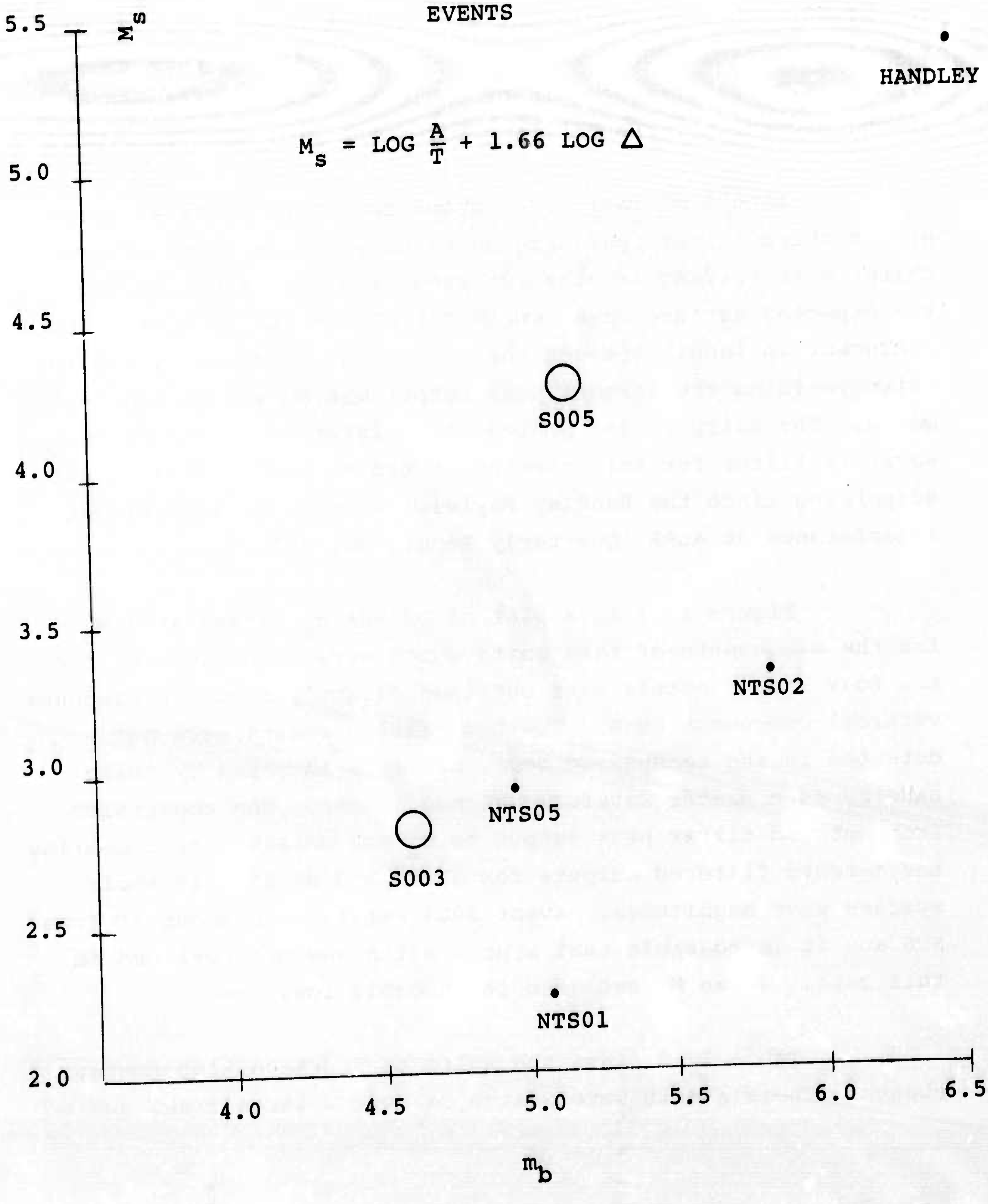


TABLE IV-2

MATCHED FILTERING RESULTS

	IMPROVEMENTS (DB)					
EVENT	VERTICAL		RADIAL		TRANSVERSE	
	.02-.075 Hz	.025-.05 Hz	.02-.075 Hz	.025-.05 Hz	.02-.075 Hz	.025-.05 Hz
HANDLEY (MW)	9.8	6.6	9.6	6.5	9.4	6.0
HANDLEY (CH)	4.9	3.0	4.7	2.9	6.0	3.0
NTS02	7.3	5.1	8.4	5.8	4.2	5.3
NTS05 (MW)	7.2	5.0	8.0	6.2	1.7	3.7

master waveform matched filtering was attempted. Table IV-4 lists the improvements obtained with chirp filters for those events which were clearly detectable on the bandpassed array processed traces. In all cases the passband of the chirp filter was 0.025 to 0.05 hz. The performance of the chirp is quite variable, but it is possible that this can be explained. The variable and generally poor performance of chirp filters for Kamchatka-Kurile events has been reported previously.[5] Chirp filters for the CA events also performed rather poorly. The great circle paths for these events crosses the Asian continental border along the northeast border of Siberia and at a small angle of incidence. Thus multipath propagation, generally detrimental to chirp filter performance, may be serve for these events. The path for WR3, for which the Rayleigh wave chirps worked quite well, leaves Siberia at a point further west and at a larger angle of incidence. Possibly multipath propagation for this path is less severe. This hypothesis is consistent with the results obtained from chirping a 48°N, 78°W event recorded at LASA. The travel path for this case leaves Siberia at almost exactly the same point as WR3, and the chirp filter worked very well.

Thus it appears that while the performance of chirps for Asian events is quite variable, it may be possible to discern a pattern as a function of the epicentral location. Since very few events have been processed, however, this conclusion is very tentative at this time. Figure IV-2 gives the M_s - m_b relationship for the eight events of this suite which were detected. All of these events are believed to be earthquakes.

D. Future Plans

Routine event processing, directed to accumulating

TABLE IV-3
SINO-SOVIET EVENTS

DATE	ORIGIN TIME	Δ (deg)	Az (deg)	m_b	DESIGNATION
6/12/70	03:05:28	39.4	270.6	4.9	KK1
6/13/70	11:48:52	39.9	271.0	5.0	KK2
6/19/70	18:52:32	24.1	274.5	5.2	KK3
6/28/70	09:36:26	32.4	270.4	4.4	KK5
6/28/70	11:01:53	28.0	270.6	5.8	KK6
6/05/70	12:00:37	69.3	4.2	4.4	WR1
6/26/70	01:56:18	73.4	351.4	4.3*	WR2
6/27/70	07:58:27	7[illegible].2	343.5	4.2*	WR3
5/31/70	03:31:54	72.5	326.8	4.1*	CA1
6/05/70	04:53:00	68.4	323.7	6.0	CA2
6/12/70	16:00:00	68.0	324.1	5.0	CA3
6/20/70	08:32:17	58.1	311.0	4.1*	CA5
6/24/70	00:43:00	73.9	305.5	4.8	CA6
6/28/70	01:57:55	61.3	326.8	5.9	CA7
6/05/70	10:31:52	27.4	296.4	5.5	NR1

* FROM SAAC BULLETIN

TABLE IV-4

CHIRP FILTER IMPROVEMENTS FOR SINO-SOVIET EVENTS

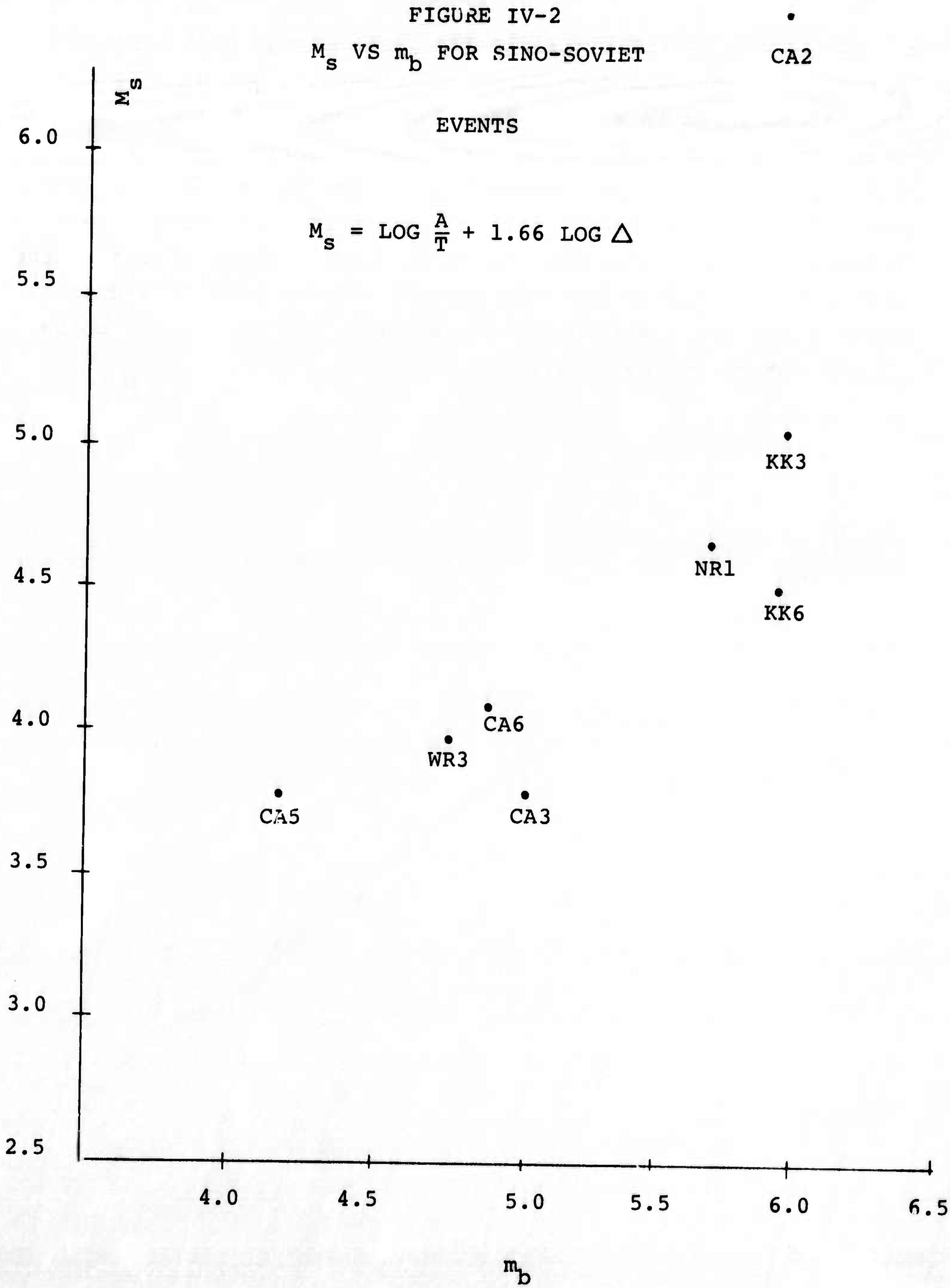
IMPROVEMENT (DB)

EVENT	VERTICAL	RADIAL	TRANSVERSE
CA2	1.7	2.3	5.3
CA3	2.1	3.3	2.1
CA5	-1.0	0.0	0.0
WR3	7.7	6.4	1.8
KK1	2.0	-0.9	
KK6	2.9	1.8	2.1

FIGURE IV-2

M_s VS m_b FOR SINO-SOVIET EVENTS

$$M_s = \text{LOG } \frac{A}{T} + 1.66 \text{ LOG } \Delta$$



a large population of discrimination parameters, will continue. Emphasis will be placed on Sino-Soviet events, but other events will be processed in some cases. One immediate goal will be to get an initial estimate of the relative performance of multichannel filter and beamsteer array processors for the presently existing array. Also the study of chirp filter performance will be continued. As large events become available the performance of master-waveform matched filters will be examined. Longer range goals will be to characterize the background noise and the nature of the signals at ALPA.

V. LONG PERIOD EXPERIMENT

A. Introduction

The basic design of the Long Period Experiment (LPE) was discussed in Quarterly Report No. 4.[4] As described, the general data processing is composed of four functions--library tape generation, quality check and edit, single station processing and analysis, and network processing and analysis. Routine processing in this experiment consists of obtaining a best waveform from each of the stations and analyzing these waveforms to determine the detection capability of the network.

B. Package Design

During the past quarter the first three processing functions were coded and checked using synthetic test data. The library tape function debug was almost completed using random test data, and an ALPA signal was reformatted into the library tape format to debug the quality check and edit programs and the single station processing and analysis programs.

The general flow for the software was shown previously in Quarterly Report No. 4,[4] but for convenience is repeated here as Figure V-1 including minor modifications. These changes are in the program LXTRAN. Previously the computation of group velocity curves and higher mode spectra was included as part of this program, but due to computer core limitations, it was necessary to include them as a separate program, LXGRP.

The programs LXMERG, LXDALL, LXSELE, LXEDIT, LXGEN, and LXTRAN were briefly described in the fourth quarterly report.[4] These programs are described in detail in this section along with the new routines LXPLOT, LXGRP, LXDISP, and LXCVTT. The program

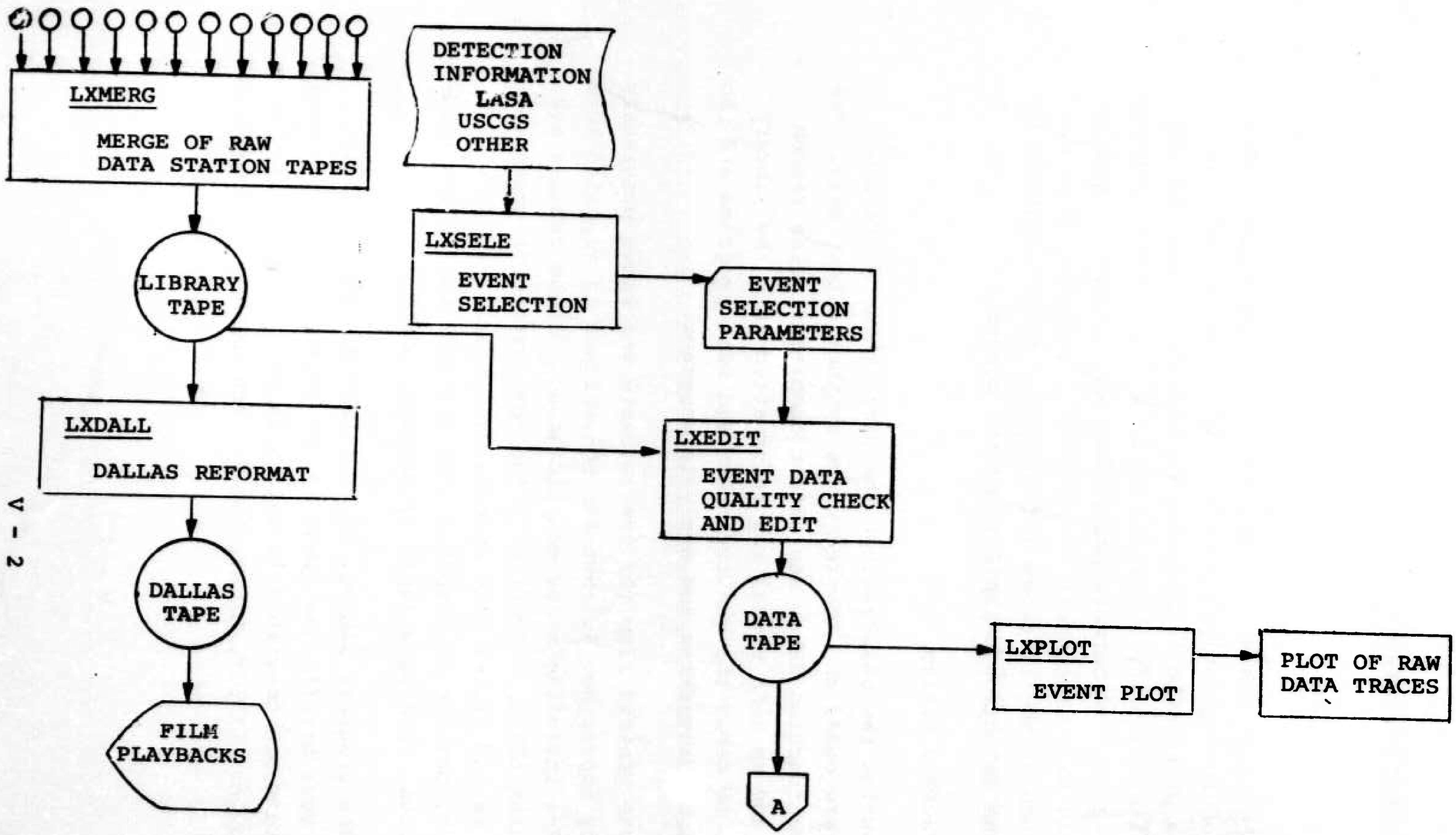


FIGURE V-1
LONG PERIOD EXPERIMENT
DATA FLOW AND MAIN
PROGRAM FUNCTIONS

PAGE 1 OF 2 PAGES

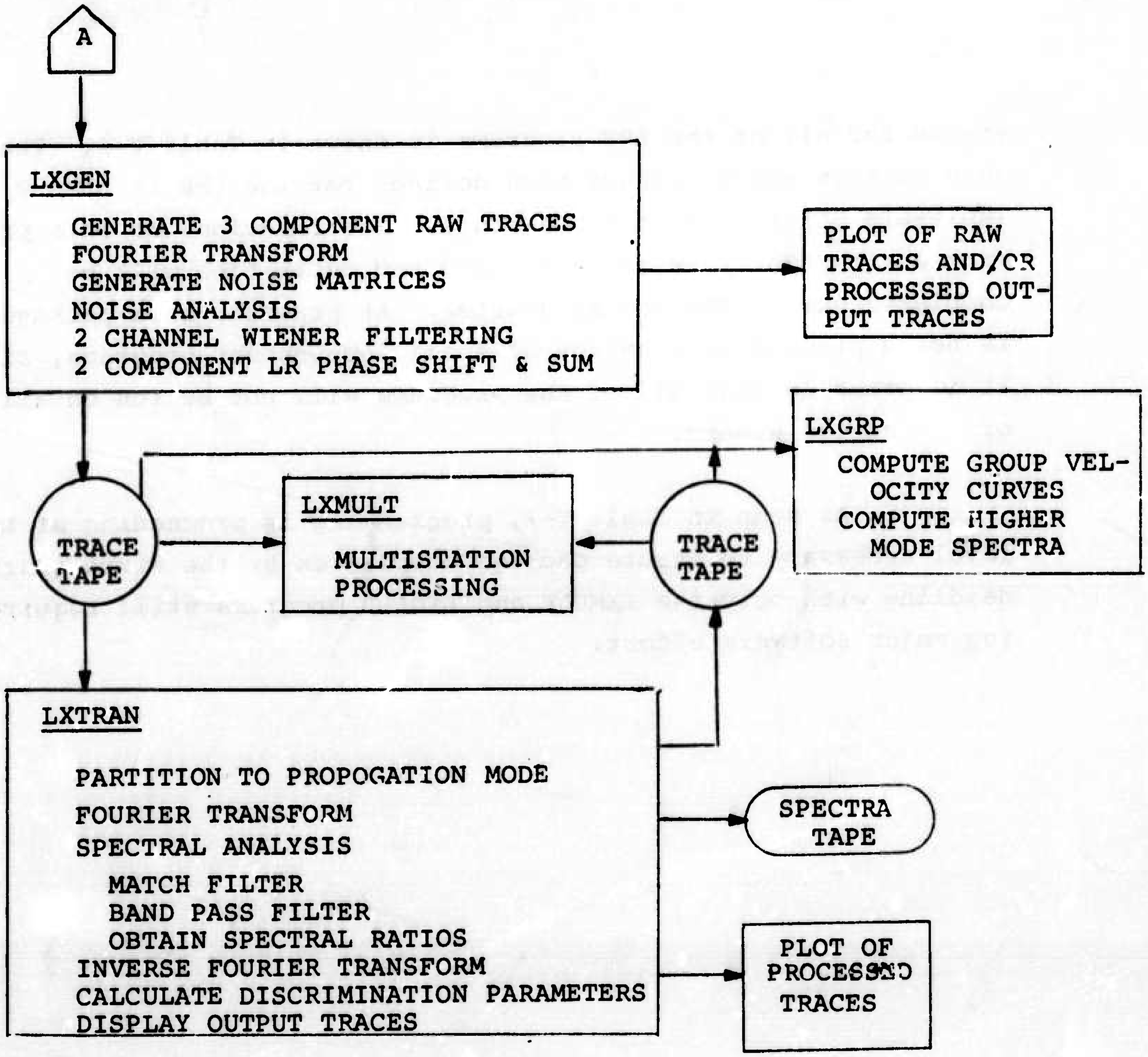


Figure V-1
LONG PERIOD EXPERIMENT
DATA FLOW AND MAIN
PROGRAM FUNCTIONS

PAGE 2 OF 2 PAGES

status for all of the LPE programs is shown in Table V-1. The only package which has not been defined for the LPE is LXMULT (Multiple Station Event Processing). The functions of this program are currently being considered and definition will be completed during the coming quarter. At present, this package is being planned as a series of small independent programs, since it is probable that all of the programs will not be run on all of the edited events.

As seen in Table V-1, programming is proceeding at the level necessary to insure package completion by the sixth quarter deadline with only the LXMULT and LXDALL programs still requiring major software effort.

TABLE V-1

LONG PERIOD EXPERIMENT SOFTWARE PACKAGES

Name	Definition Status	Coding and Debug Status
LXMERG[M]	Complete	Debug almost complete
LXDALL	Complete	Some coding done
LXSELE	Complete	Debug complete
LXEDIT[M]	Complete	Debug complete
LXPLOT	Complete	Debug complete
LXGEN[M]	Complete	Debug complete
LXTRAN[M]	Complete	Debug complete
LXGRP	Complete	Debug almost complete
LXDISP	Complete	Debug complete
LXCVTT	Complete	Debug complete
LXMULT	Not defined	No action

Note: "M" denotes a major software effort.

1. LXMERG

The function of the LXMERG program is to merge up to fifteen long period experiment field tapes into a single multiplexed library tape, performing the appropriate time alignment, decimation, decoding, and extraction operations. In the discussion that follows, the term "tape" is to be understood as a tape volume, which may consist of from one to three physical reels of tape. Thus the merge program can accept up to three consecutive reels of tape from each of fifteen field stations, and merge these data onto up to three reels of output tape.

Since hardware availability permits the simultaneous use of only two seven-track tape transports and five nine-track transports, the program has been written as a multipass merge, consisting of from one to eight phases, depending on the number of field tapes to be read. Figure V-2 shows the merge tree used for the eleven tape case, and illustrates the basic approach of the program. In each merge phase, one or two field tapes are read, and the necessary decoding, decimation and extraction operations are performed. The data are output, on all phases except the last, in a packed intermediate format, together with any data from a preceding phase read in order to free a transport for use in a subsequent phase. On the final phase of the merge, the packed data are unpacked and remultiplexed for output in the final library format. The sequencing of the merge phases is chosen so as to minimize the number of times data are read and rewritten. The fifth nine-track tape unit is reserved for displacement data extraction, as described below.

Program control is by punched data card. The number of tapes to be merged is specified, together with the six byte serials for each tape reel. The program can be restarted at

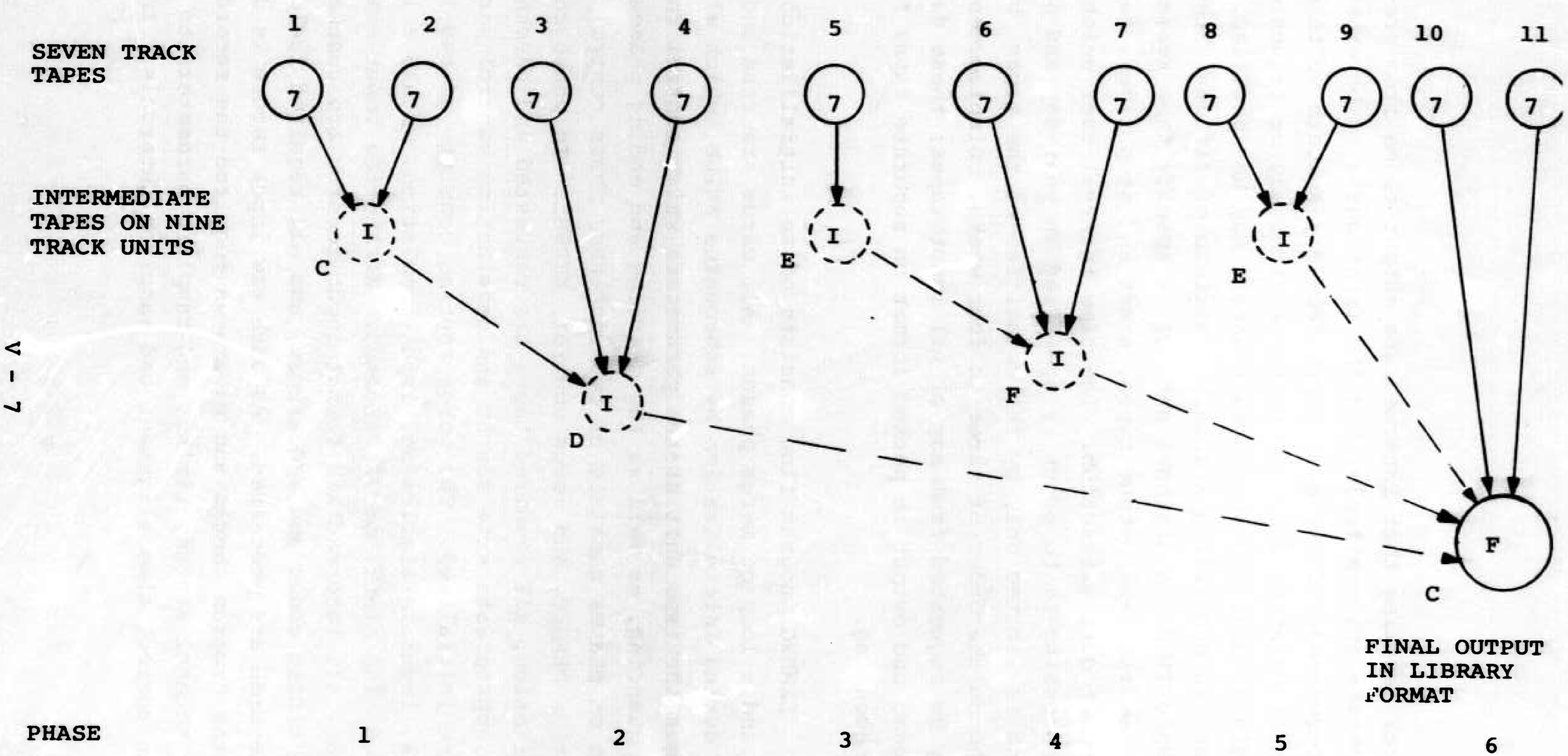


Figure V-2
PROGRAM LXMERG
SAMPLE MERGE TREE

any phase, assuming that intermediate output tapes from preceding phases are available, and the first phase to be executed can be requested. Since each input tape may contain up to nine channels of velocity data, up to three sites may be requested from a given tape, and any three channels may be specified, in any order, as comprising a site. A maximum of fifteen sites may be specified. Additional data cards specify tape serials for intermediate and output tapes, start and stop times, and displacement data extraction. The time interval over which merge processing is to occur is specified in year-day and seconds, and is limited only by the capacities of the tapes but should be on the order of three to four weeks. Displacement data may be requested from any or all input tapes; these data are decoded and output in packed format on separate tapes for later processing.

LXMERG program flow consists of an initialization routine and a loop on merge phases. All cards are read and checked during initialization by subroutine SETUP, which also determines the tape unit status parameters which control the merge sequencing, as well as the starting and ending phases. The loop on phases consists of two routines, phase control initialization PHASEC, and merge control, KERNEL. In phase control initialization, all required tapes are requested and checked, and the appropriate site source and destination control parameters are initialized. The merge routine consists of two loops on sites, input initiation and input completion, within a loop on output time blocks of 720 seconds. Within the input completion loop, all intermediate format input records are checked for correct timing codes and I/O errors, and all required field tape input records are processed. As each raw input record is decoded, the program checks and resets as required the record length, channel status, timing, and sampling parameters to maintain correct time alignment and sampling intervals. Input

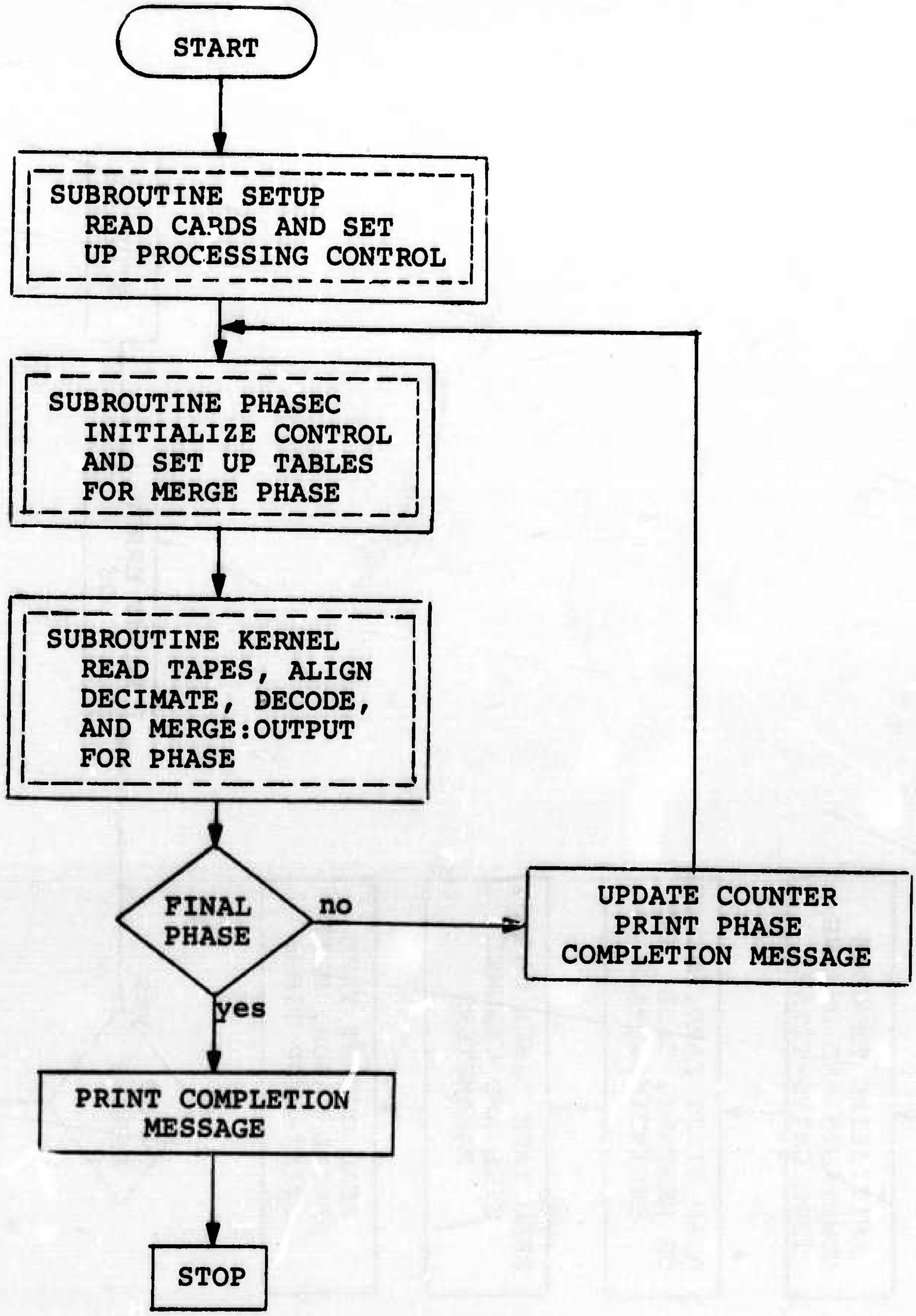


Figure V-3
GENERAL FLOW
LXMERG

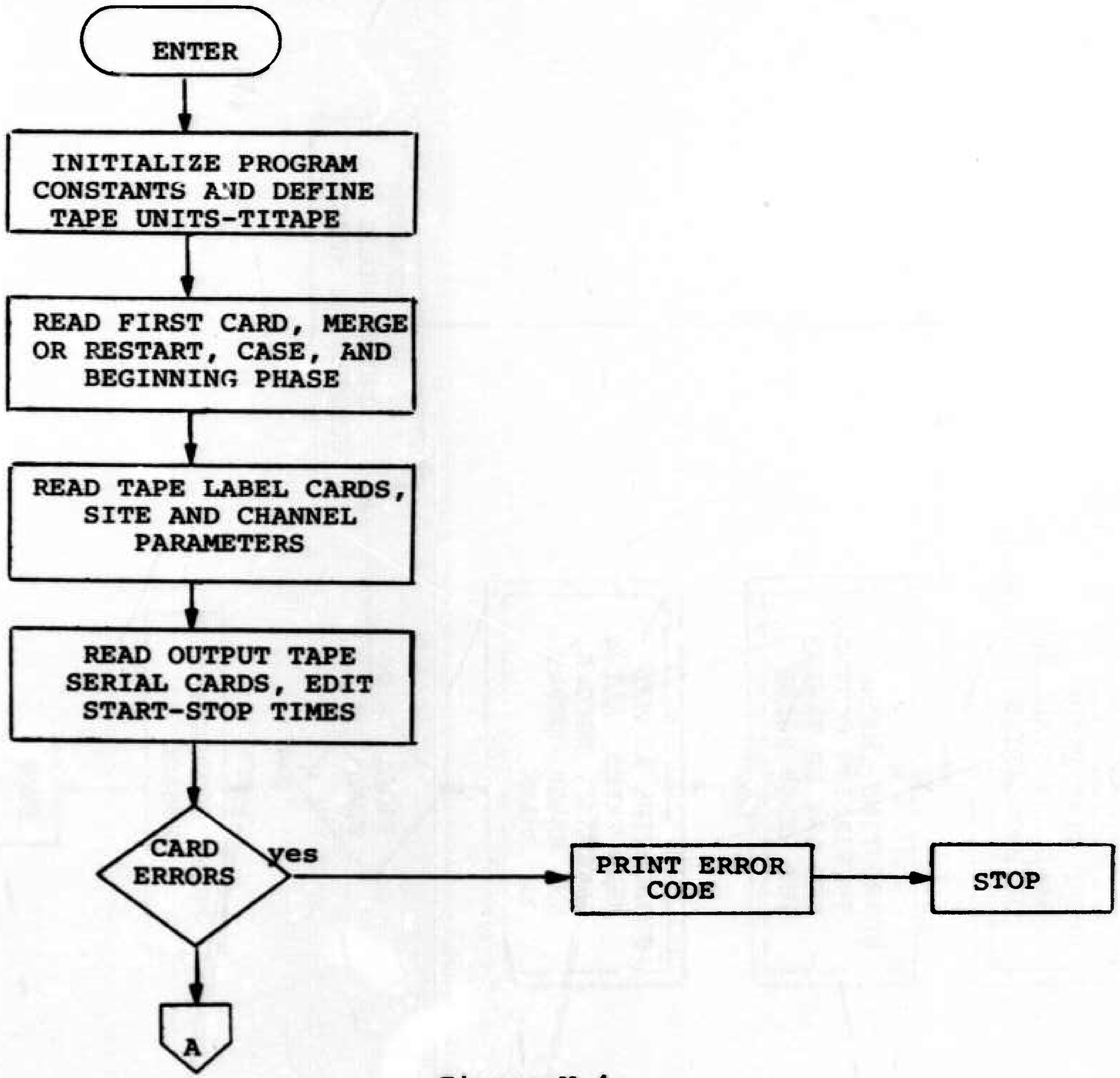


Figure V-4

SUBROUTINE SETUP
1 of 2 pages

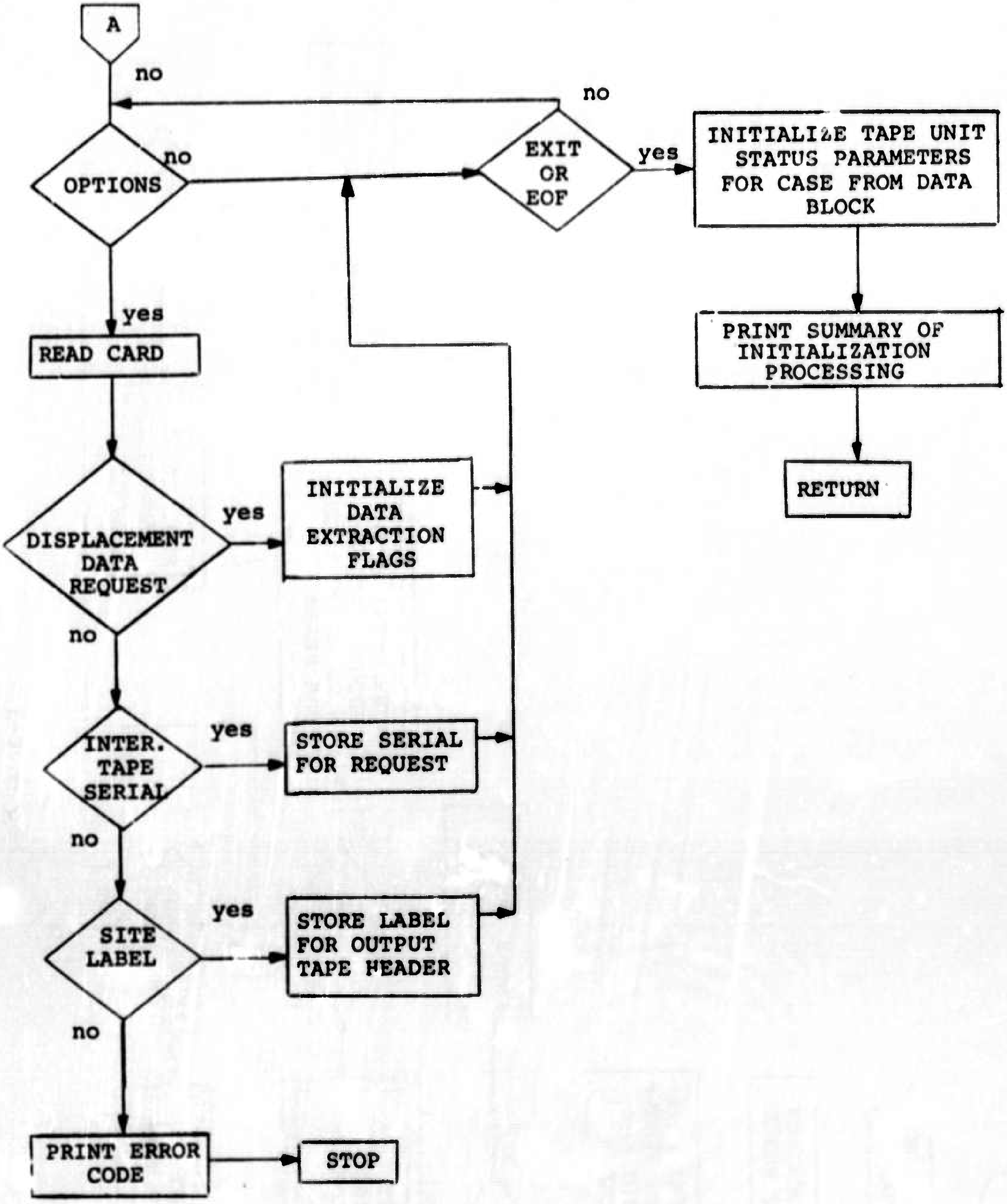


Figure V-4

SUBROUTINE SETUP
2 of 2 pages

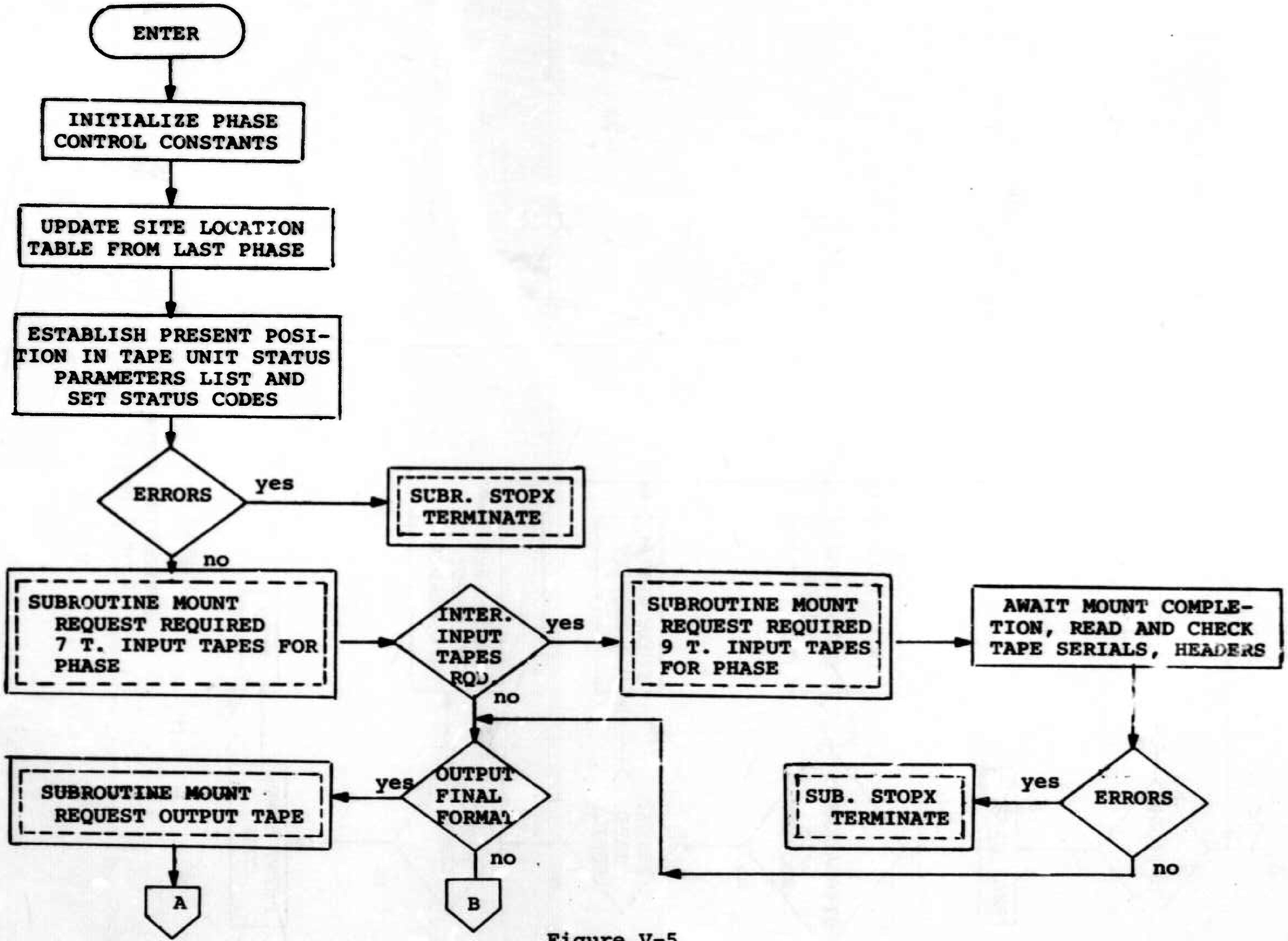


Figure V-5
SUBROUTINE PHASEC
1 of 2 pages

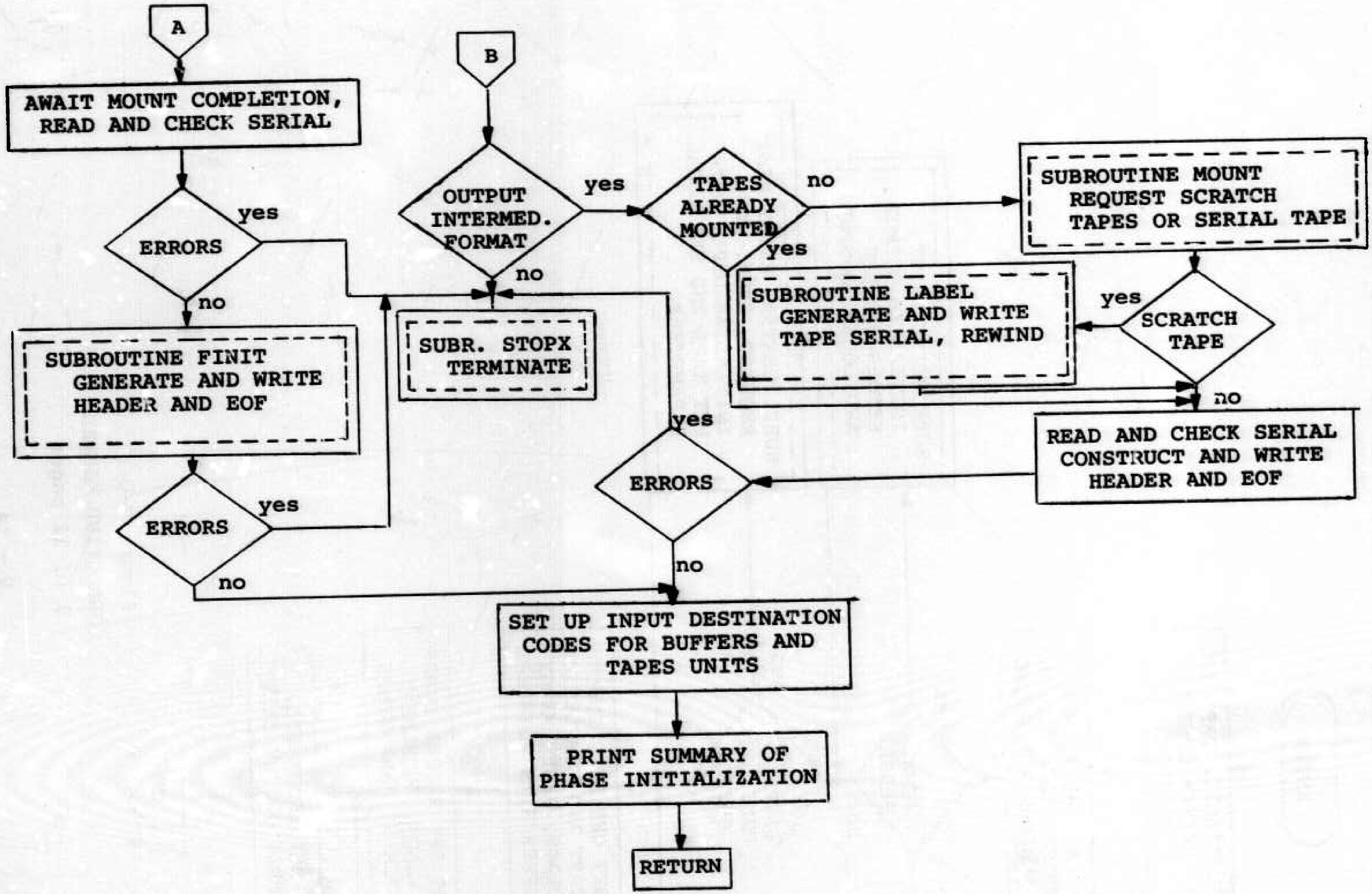


Figure V-5

SUBROUTINE PHASEC
2 of 2 pages

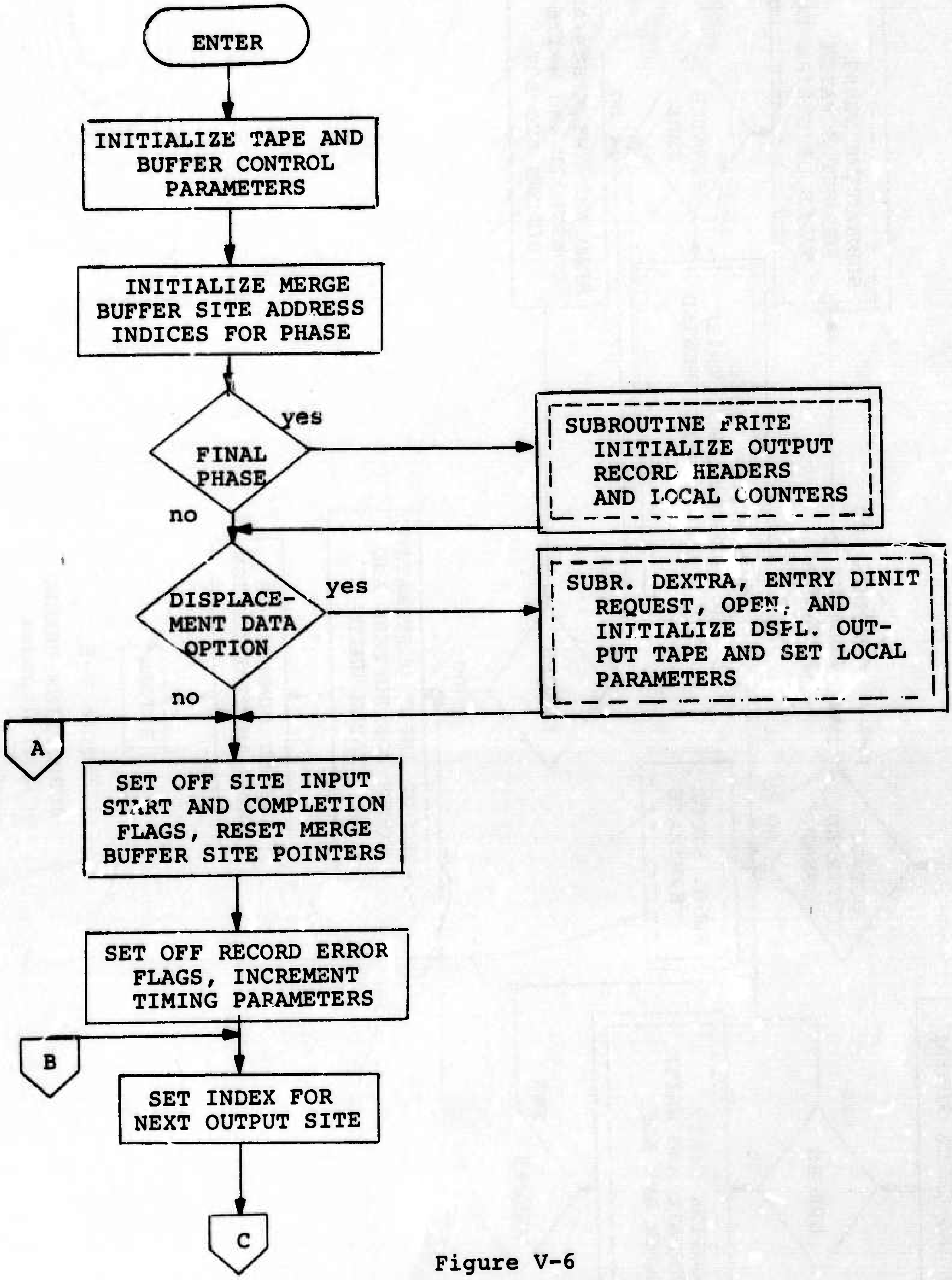


Figure V-6
SUBROUTINE KERNEL
1 of 12 pages

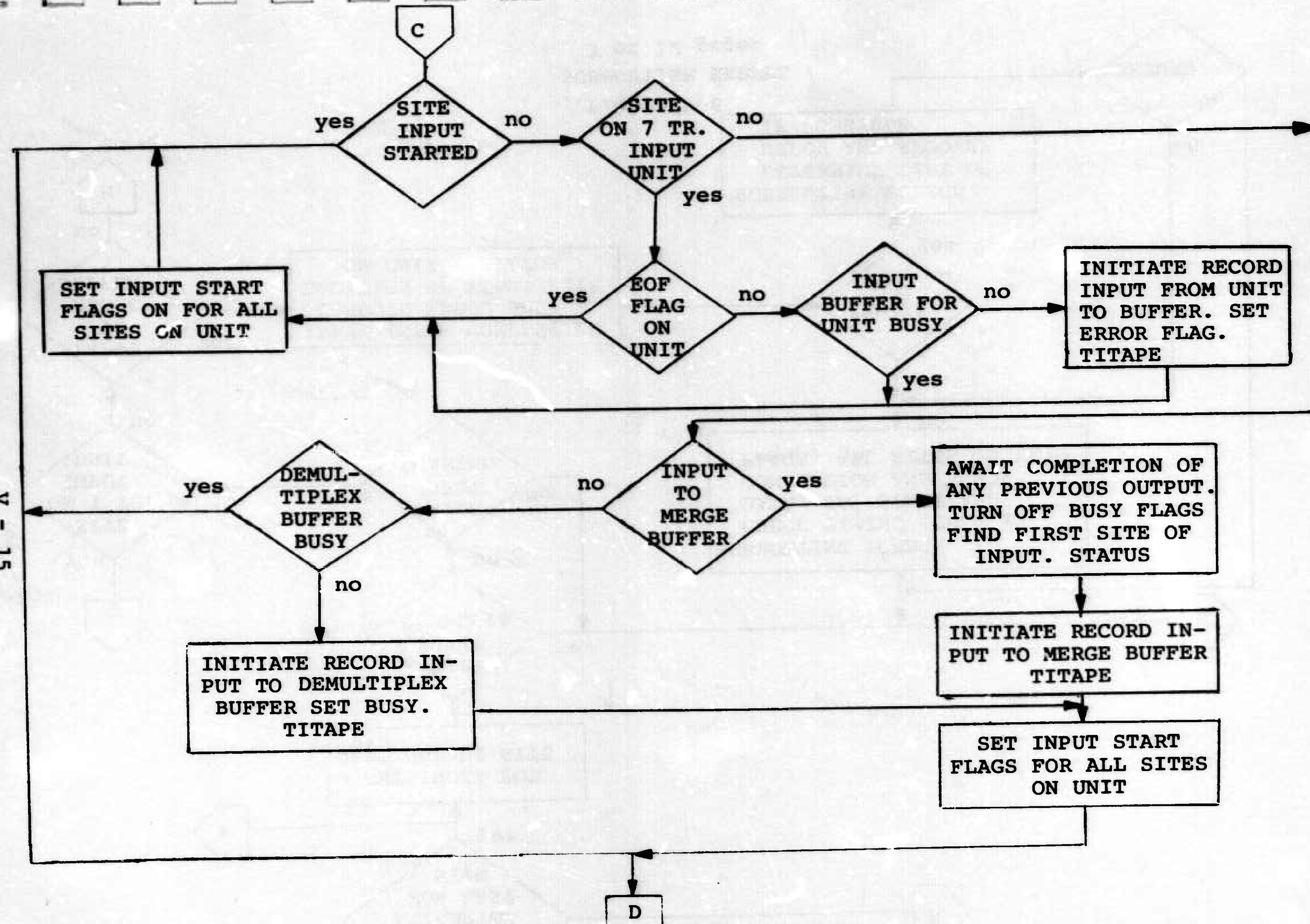


Figure V-6
SUBROUTINE KERNEL
2 of 12 pages

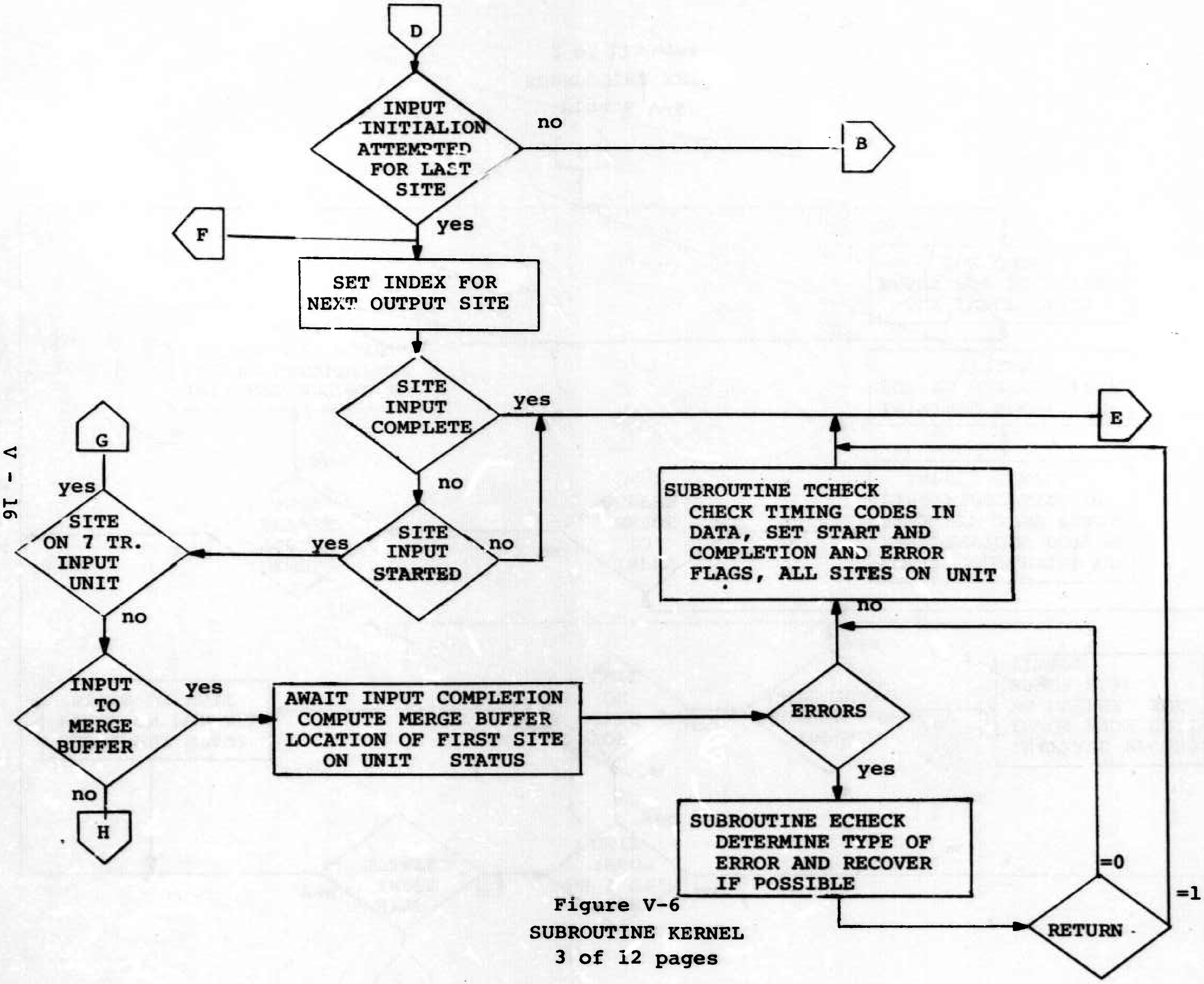


Figure V-6
SUBROUTINE KERNEL
3 of 12 pages

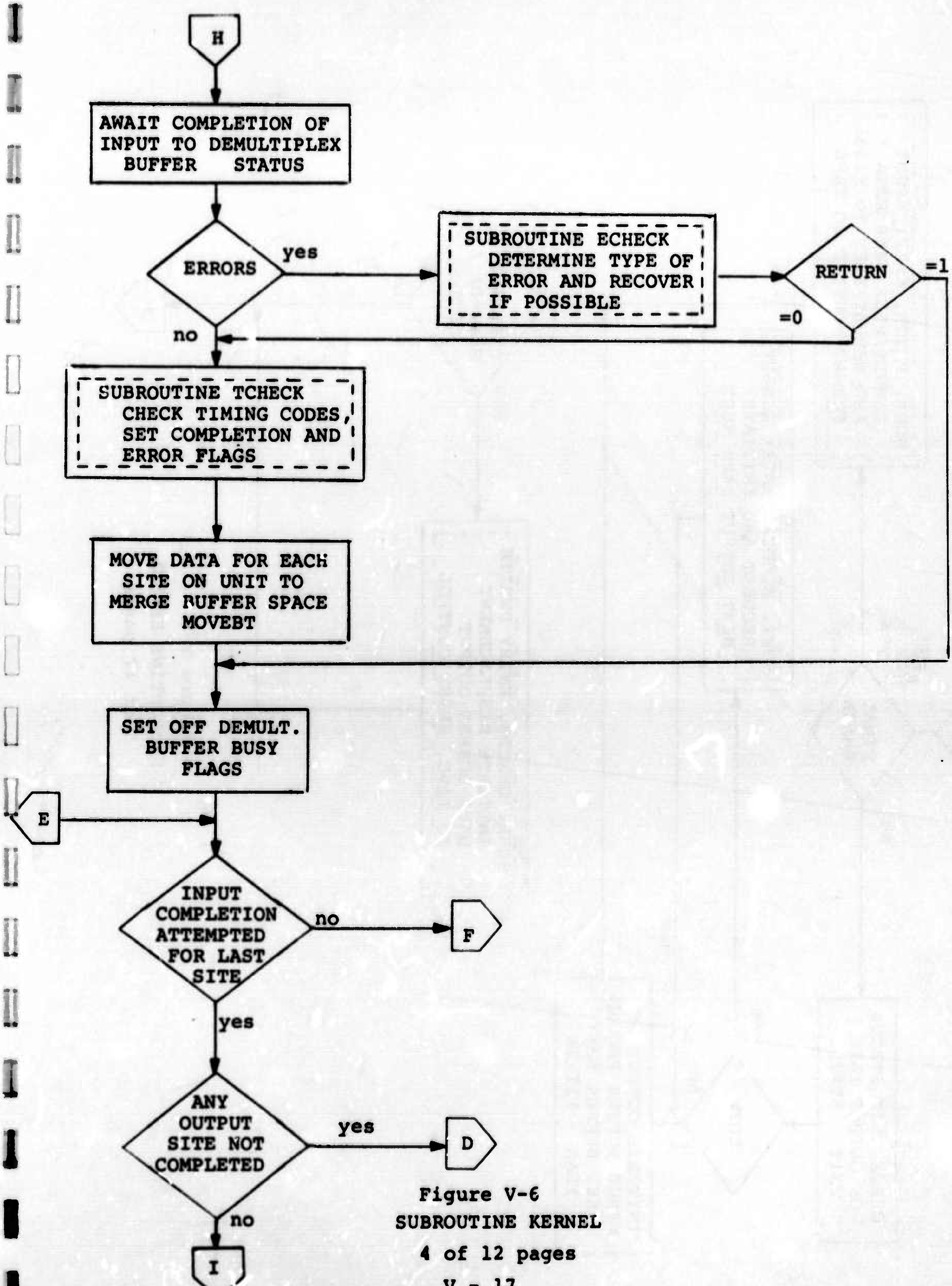


Figure V-6
SUBROUTINE KERNEL
4 of 12 pages

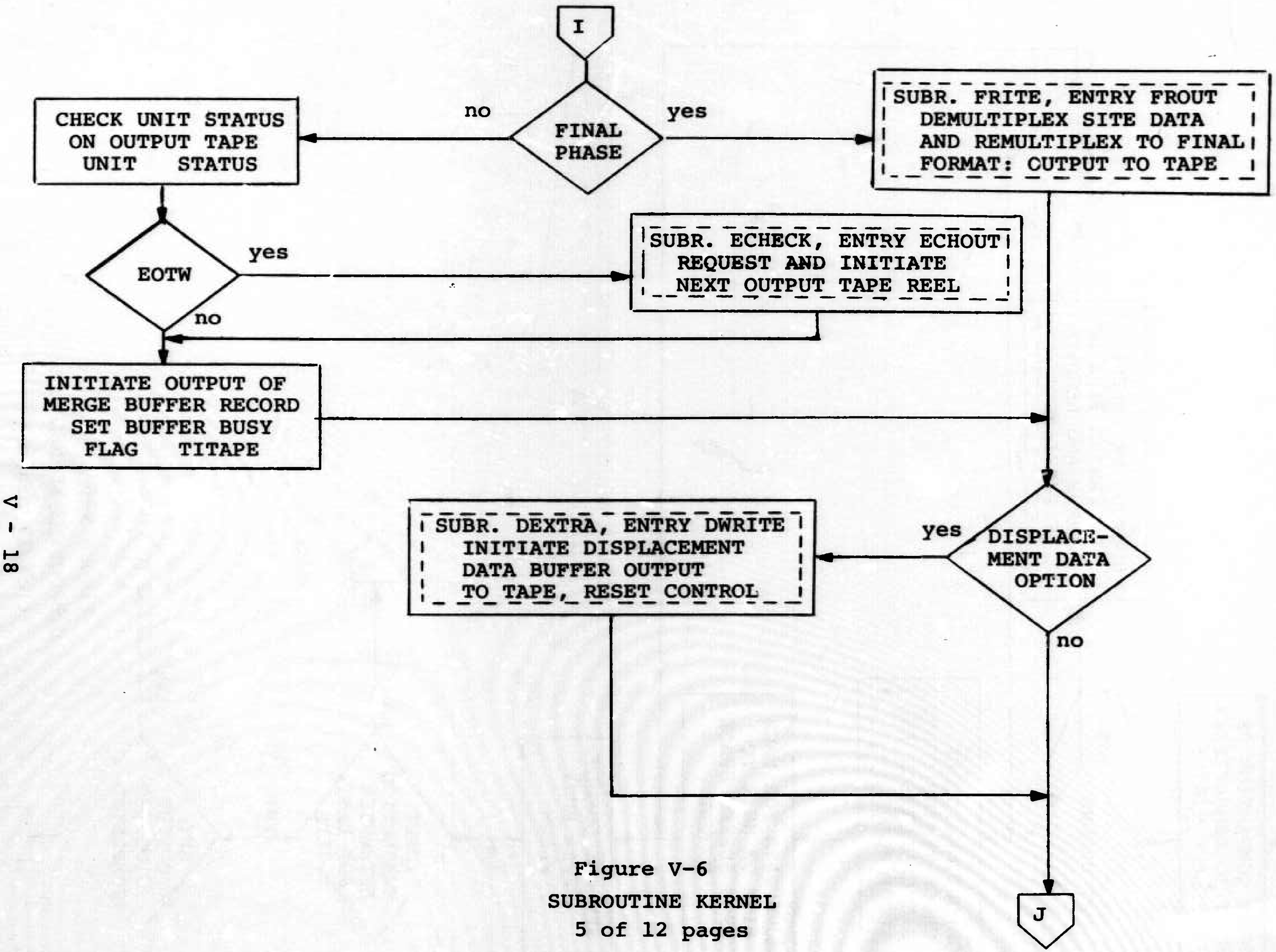


Figure V-6
SUBROUTINE KERNEL
5 of 12 pages

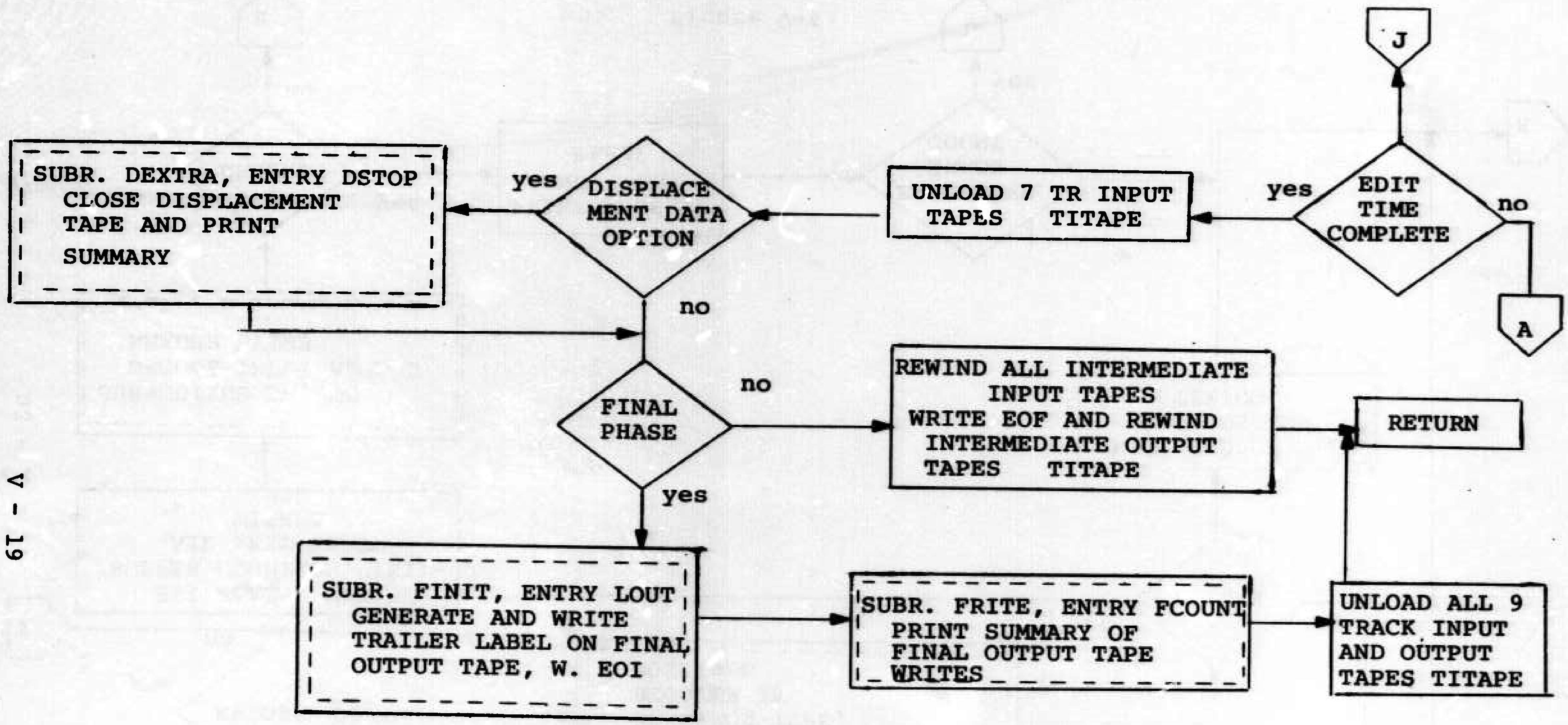


Figure V-6

SUBROUTINE KERNEL
6 of 12 pages

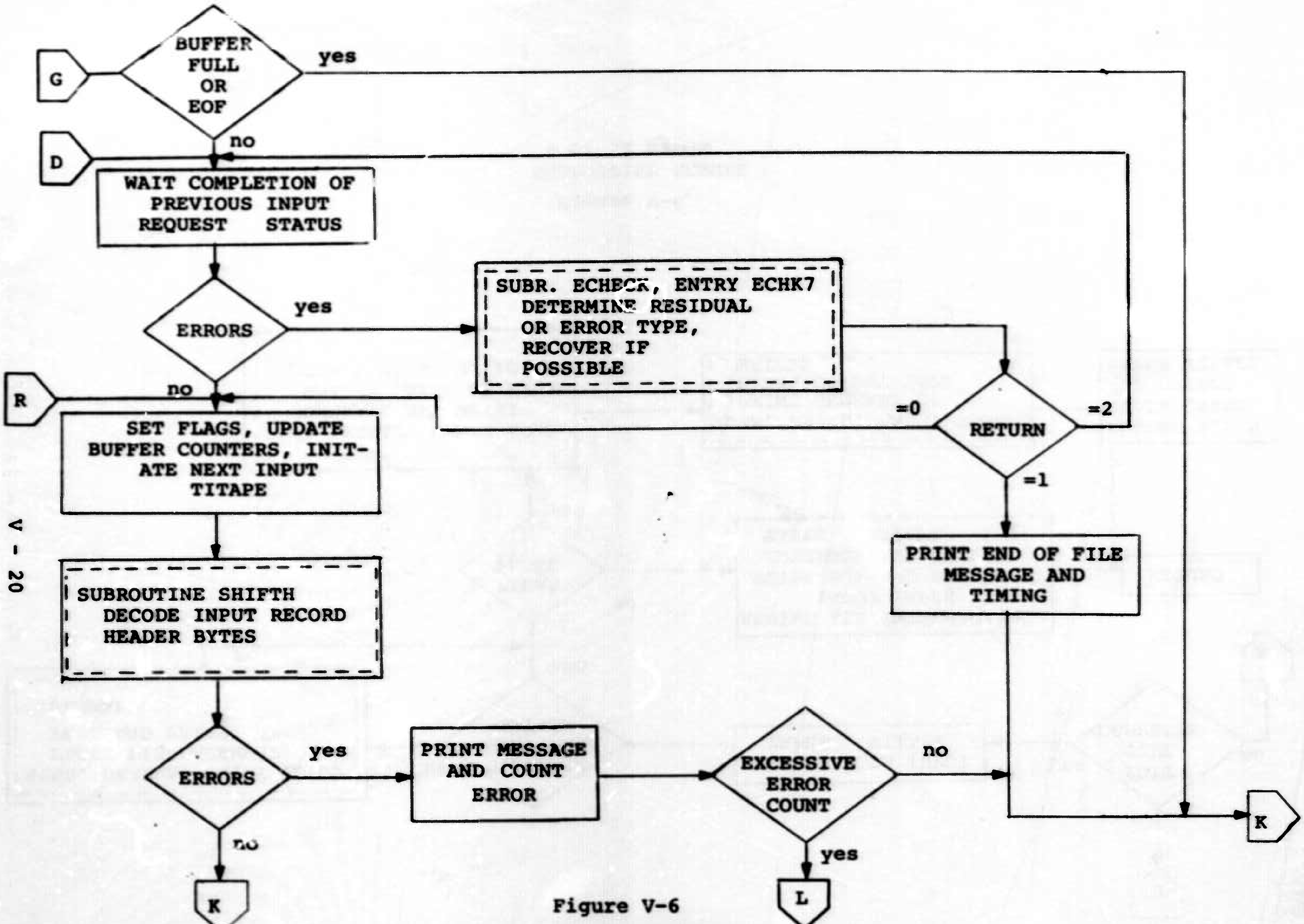


Figure V-6

SUBROUTINE KERNEL

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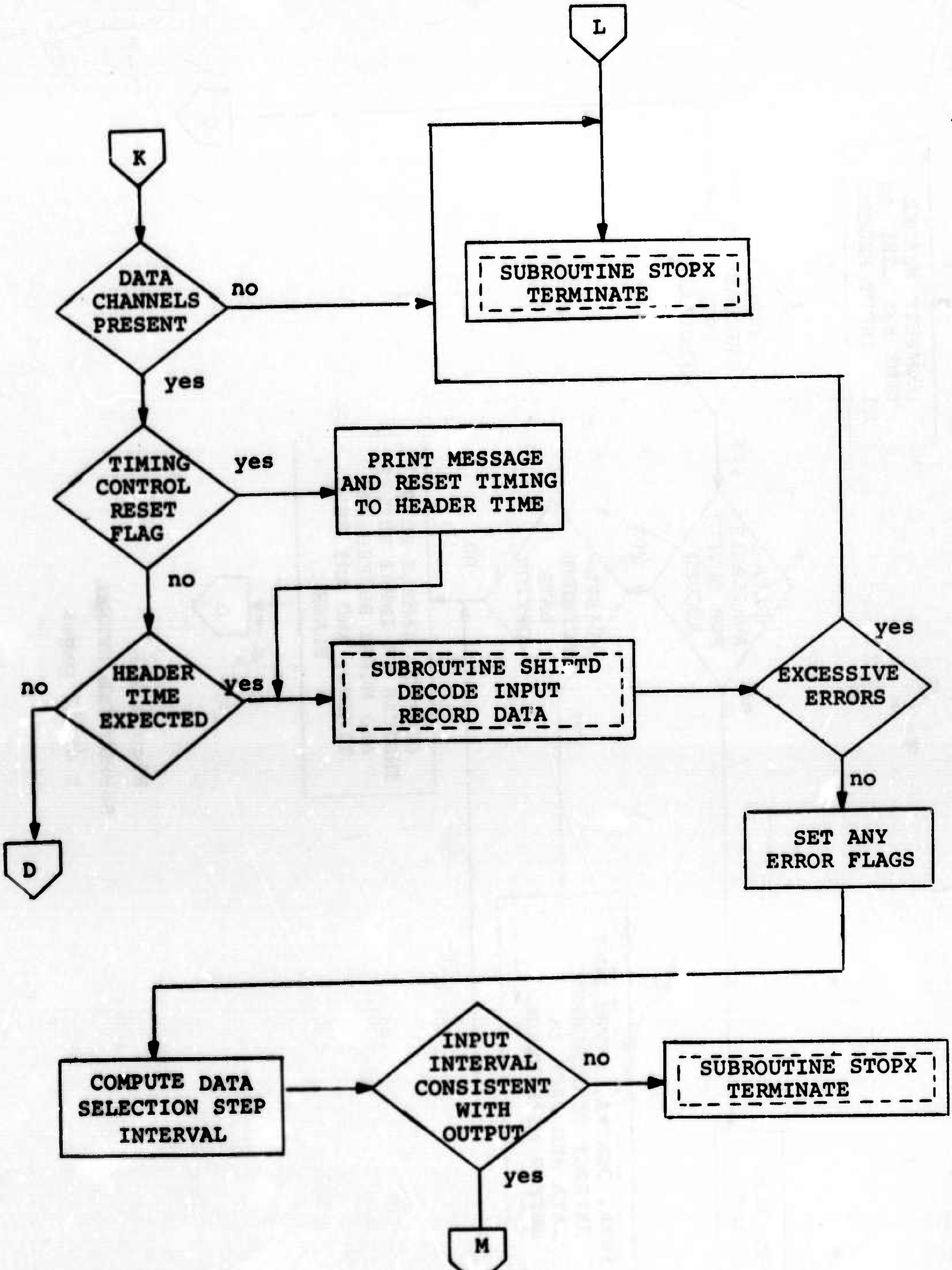


Figure V-6
SUBROUTINE KERNEL
8 of 12 pages

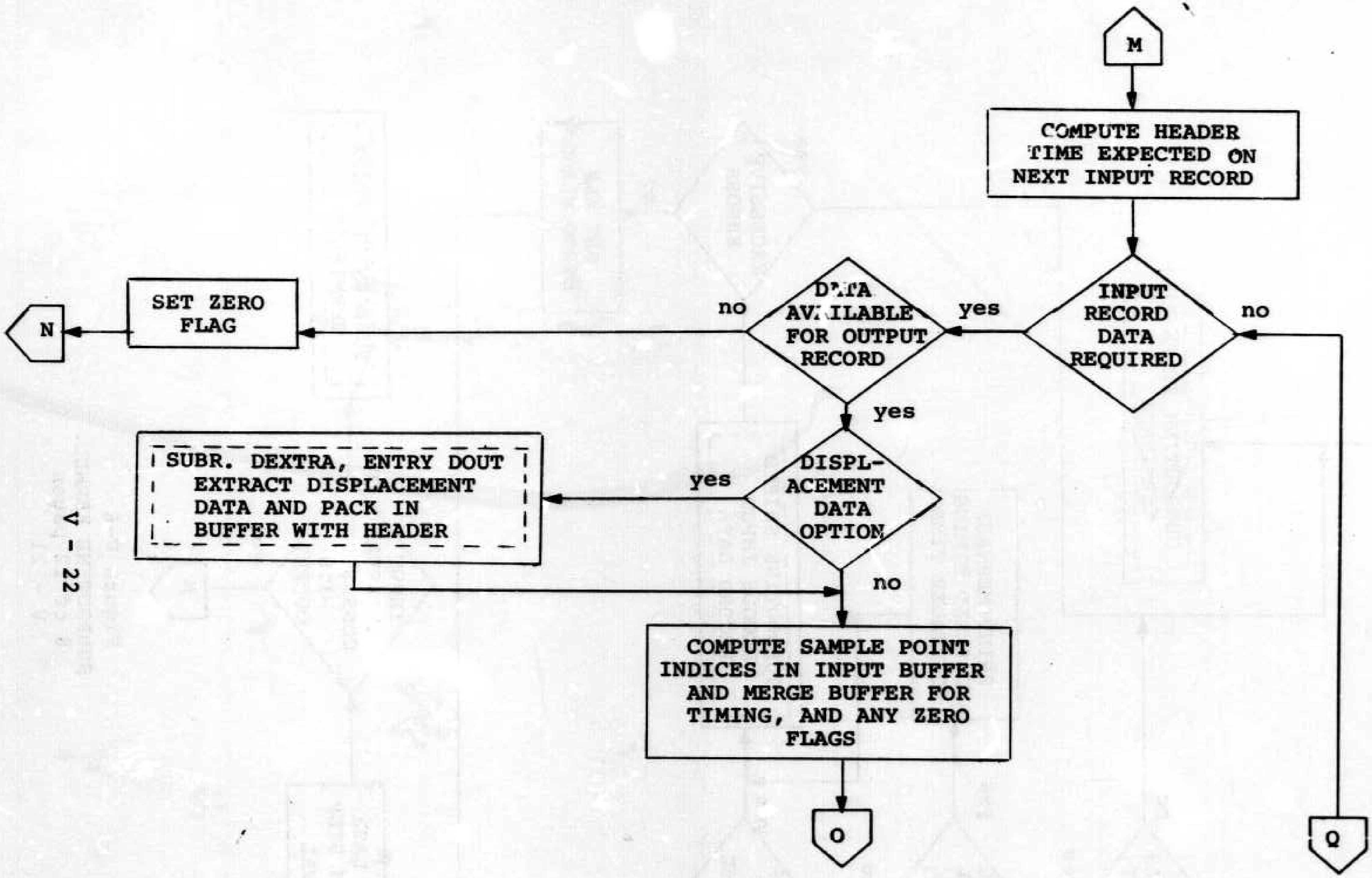


Figure V-6
SUBROUTINE KERNEL
9 of 12 pages

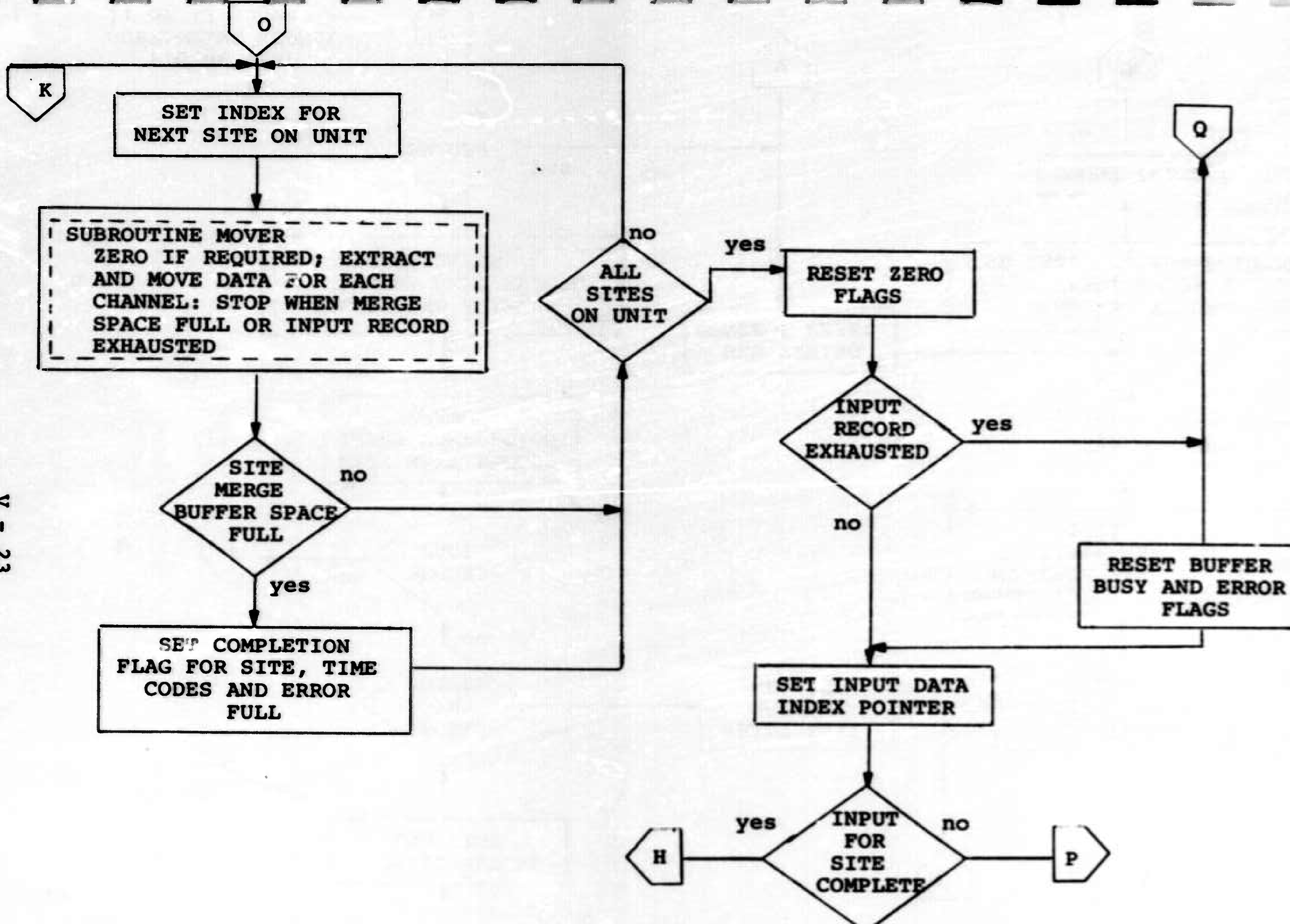


Figure V-6
SUBROUTINE KERNEL
10 of 12 pages

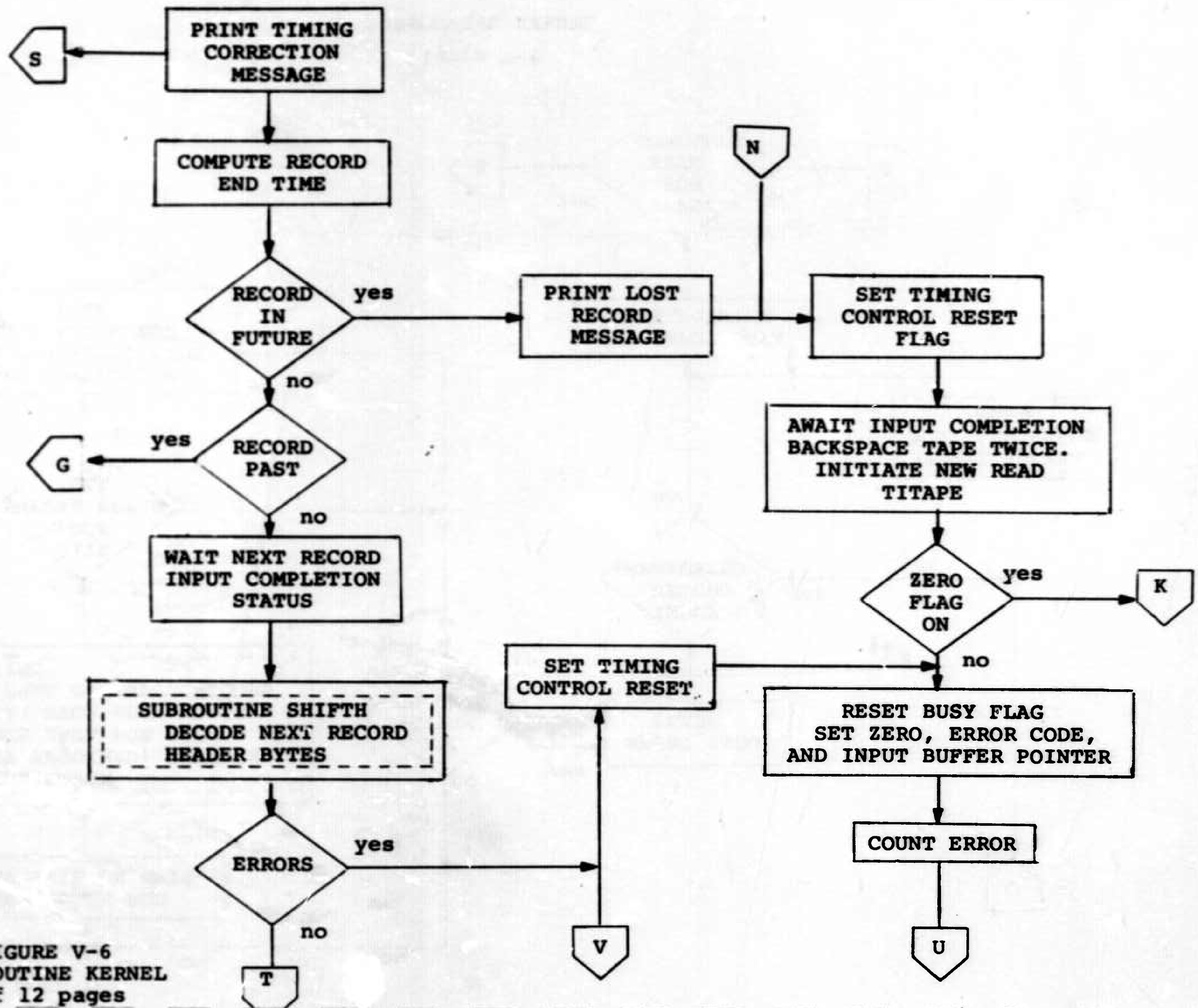


FIGURE V-6
SUBROUTINE KERNEL
11 of 12 pages

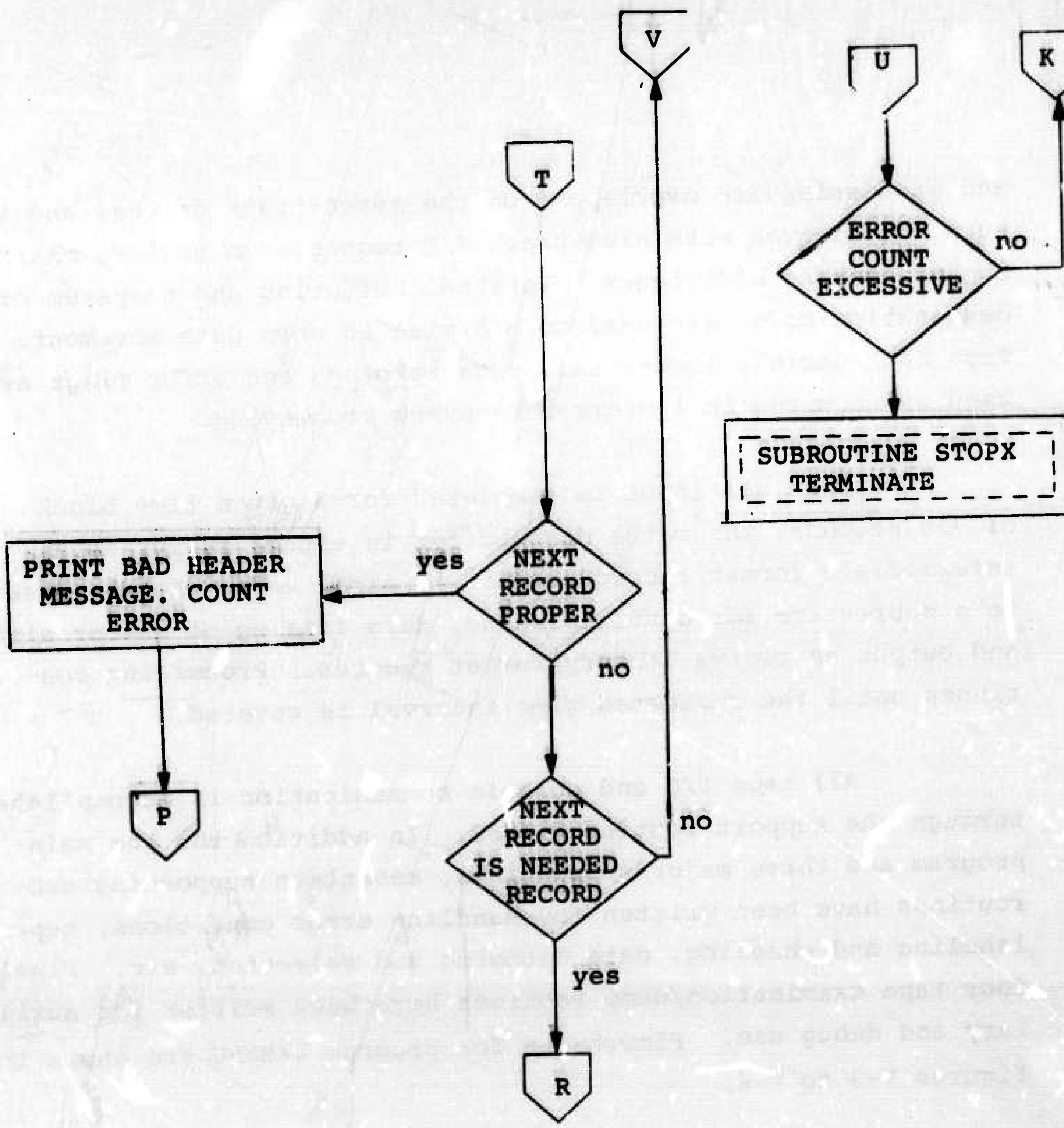


Figure V-6
SUBROUTINE KERNEL
12 of 12 pages

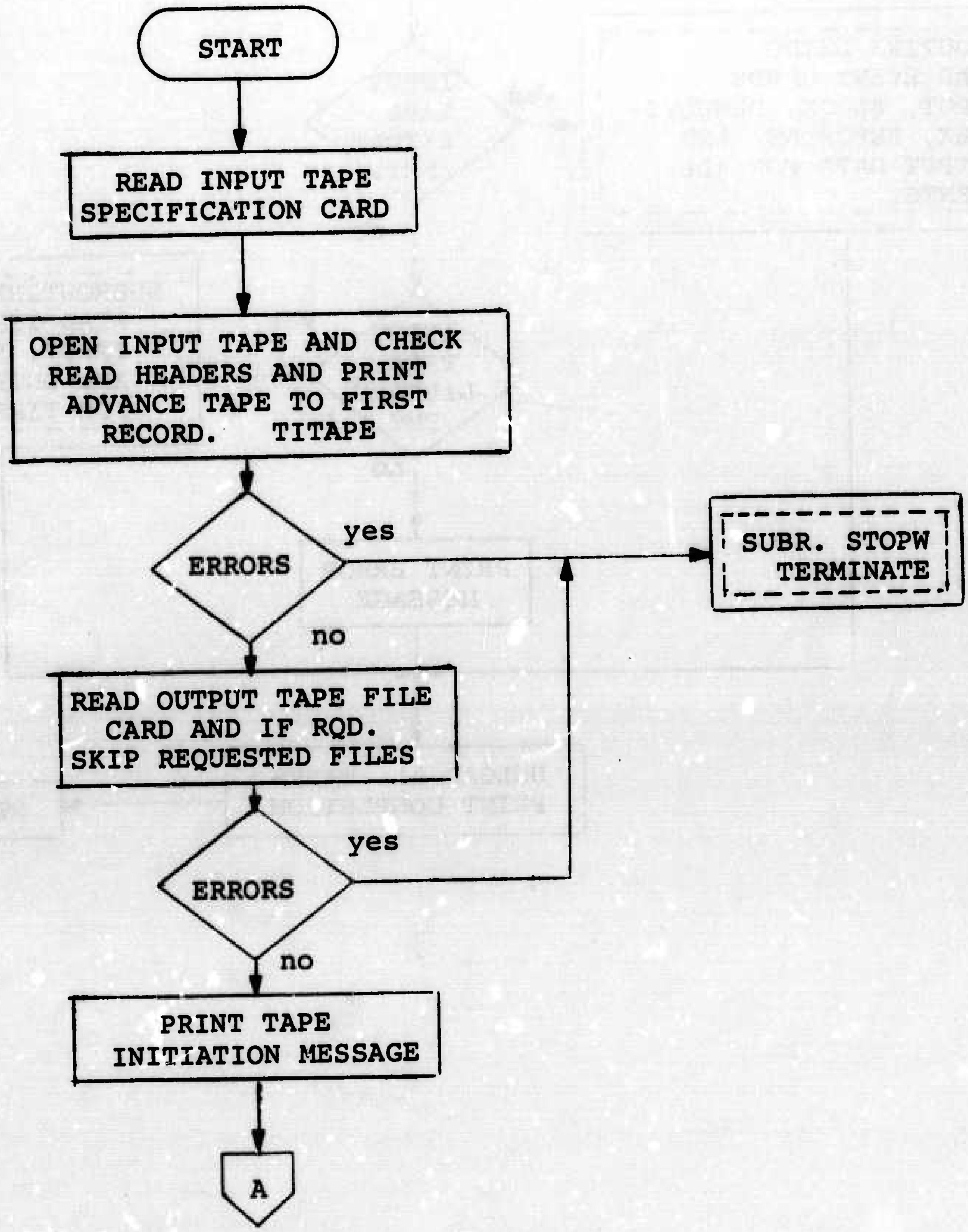
and processing are overlapped on the seven-track drives, and in turn interleaved with nine-track I/O requests to achieve maximum processing efficiency. Internal buffering and a system of destination codes are used to minimize in core data movement. Tape backspacing, look-ahead, data zeroing, and error flags are used as required in I/O error recovery processing.

When all input is completed for a given time block of 720 seconds, the merge data buffer is either output as an intermediate format record, or, if in final merge phase, passed to a subroutine for demultiplexing, zero filling of absent sites, and output as twelve library format records. Processing continues until the requested time interval is covered.

All tape I/O and console communication is accomplished through the support routine TITAPE. In addition the the main program and three major subroutines, seventeen supporting subroutines have been written for handling error conditions, tape labeling and checking, data decoding and selection, etc. Finally, four tape examination/dump routines have been written for auxiliary and debug use. Flowcharts for program LXMERG are shown in Figures V-3 to V-6.

2. LXDALL

The function of the LXDALL program is to generate the seven-track, 556 bpi data tapes required for film playback in the long period experiment. Input tapes may be either the library tape format (velocity or displacement data as output from the LXMERG program) or the LXTDAT format (time domain data output from the LXEDIT program). Output is in the form of a series of tape files, one file for each input time interval or event specified; a skip option permits the addition of files to earlier output tapes, as well as providing restart capability.



Figur

GENERAL FLOW
LXDALL
1 of 2 pages

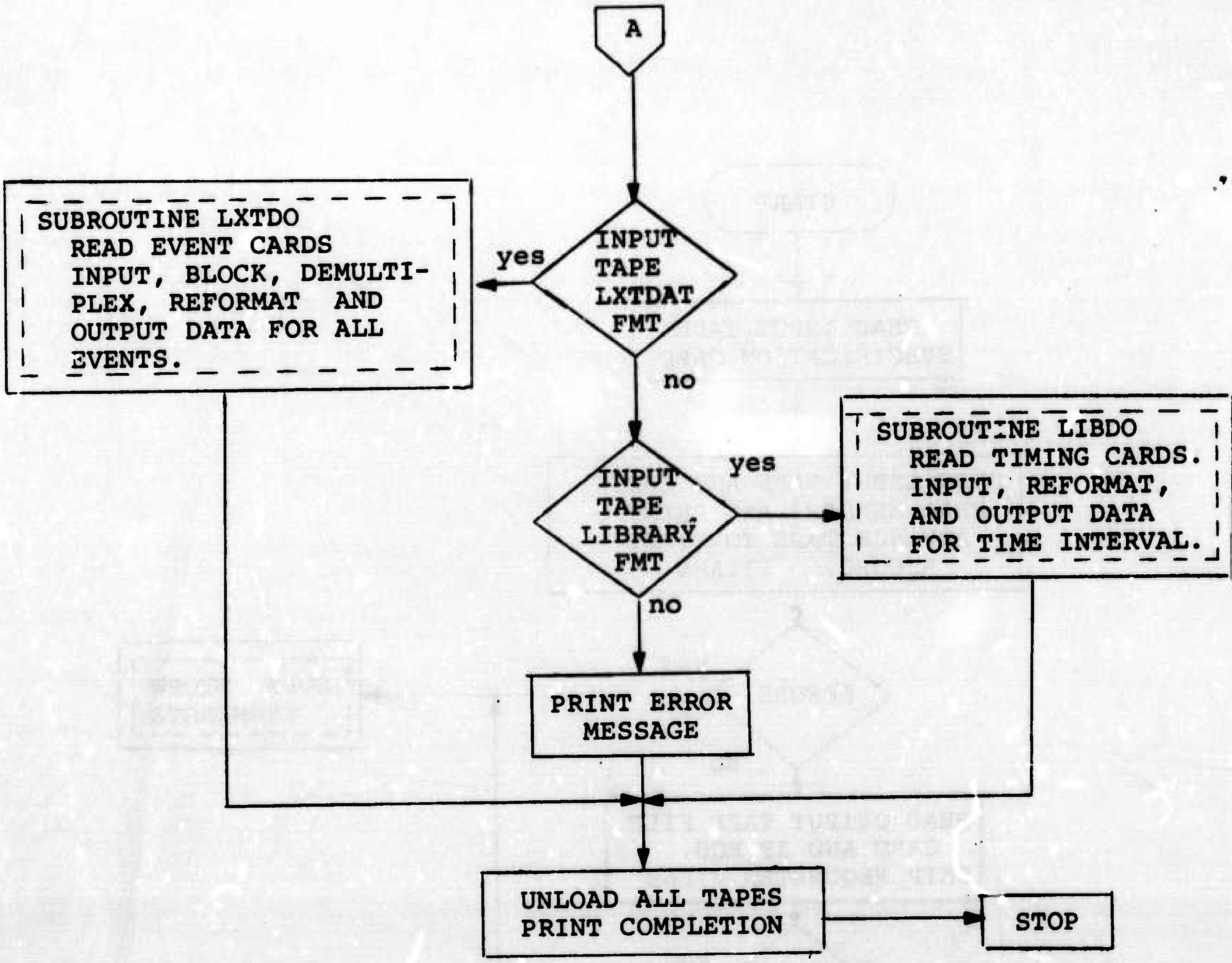


Figure V-7
GENERAL FLOW
LXDALL
2 of 2 pages

The program flow consists of the main program LXDALL, which reads the tape specification cards, opens and positions both input and output tapes, checks serials, and determines which of the two input tape formats is being used, and two major subroutines, LIBDO and LXTDO. If the input tape is in LXTDAT format, LXTDO is called; this routine consists of a loop on events, within which each event specified on data cards is located on the input tape, remultiplexed from (POINTS, COMPONENTS, SITES) to (COMPONENTS, SITES, POINTS), sectioned into blocks of thirty sample points, integerized and reformatted to twelve-bit halfwords, and output to tape.

If the input tape is in the library format, LIBDO is called, which reads the time interval specified on data cards and constructs a loop on input records required to cover the specified interval. Within this loop on records, the data is input, extracted, reformatted, and output. A dump option permits the printing of the input tape record headers.

Both major subroutines use overlapped input, processing, and output, and share a group of common subroutines for error checking and recovery, timing code and header generation, data reformatting, etc. All tape input and output is through the support routines TIINTP and TITAPE. LXDALL flowcharts are shown in Figures V-7 to V-9.

3. LXSELE

As described in Quarterly Report No. 4[4], this program uses the PDE or other source information to calculate the event edit parameters. The purpose of the program is to show the analyst what data will be edited in LXEDIT before he performs the actual data edit and to check the LXEDIT input data cards for errors.

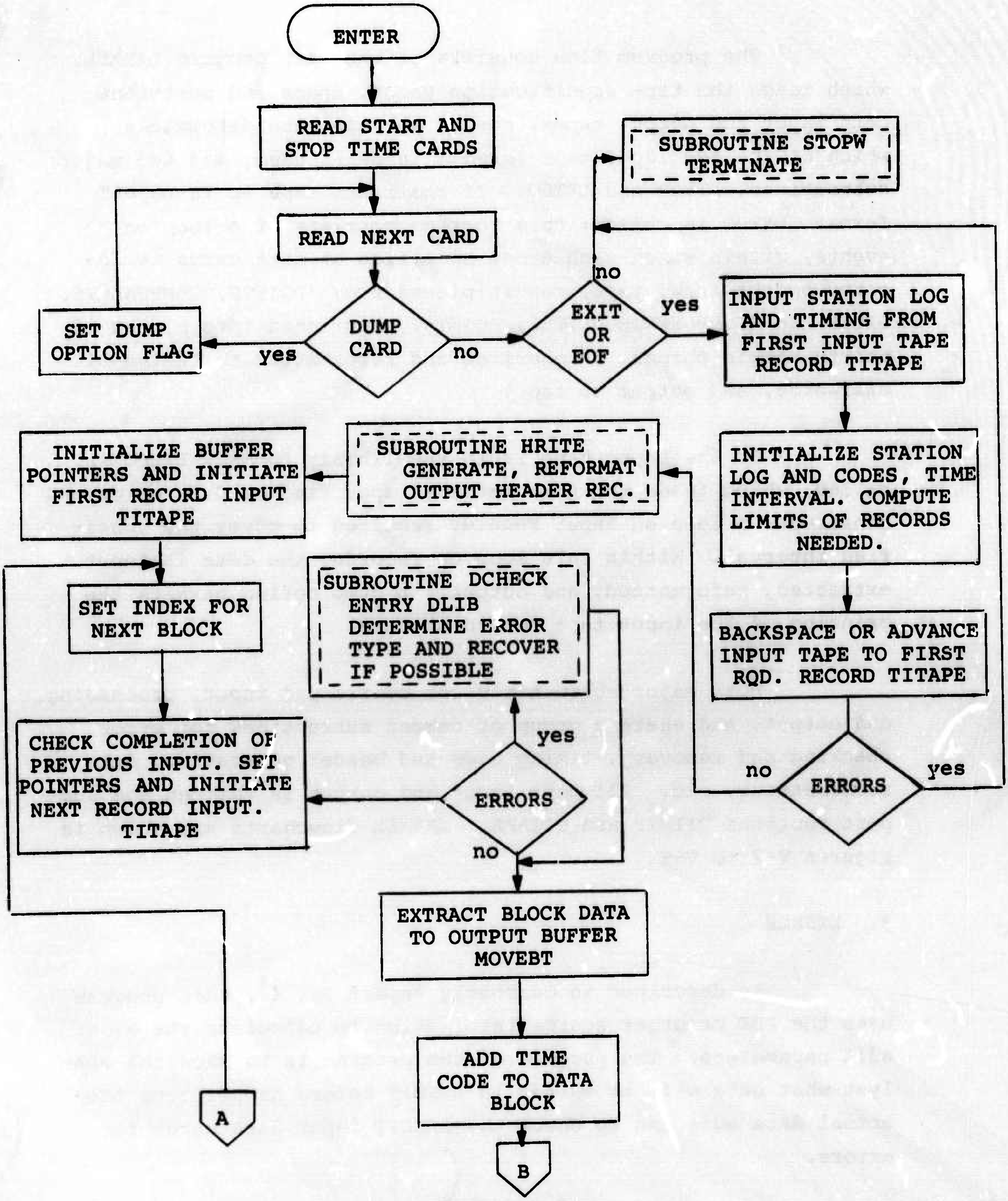


Figure V-8
SUBROUTINE LIBDO
1 of 2 pages

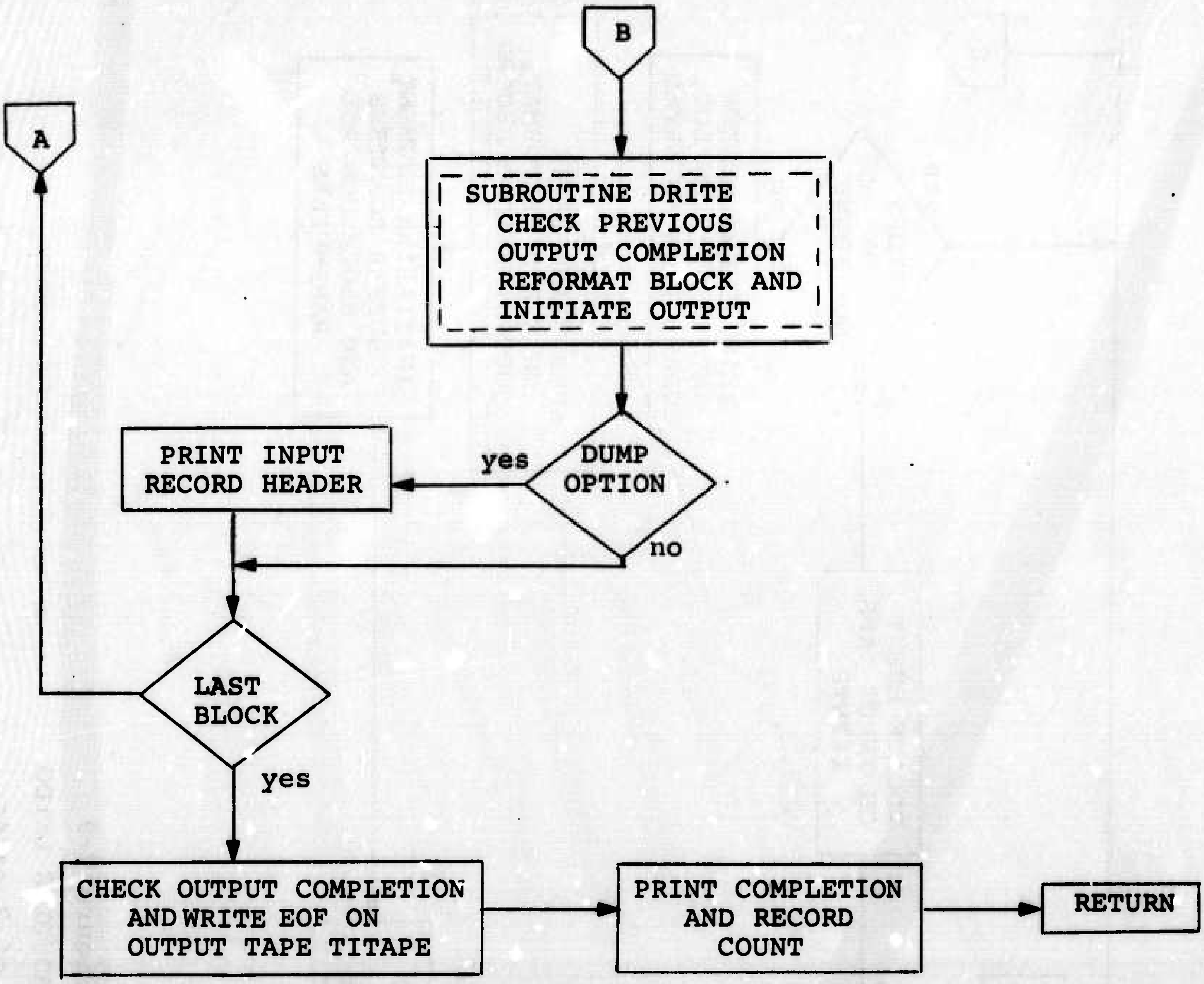


Figure V-8
SUBROUTINE LIBDO
2 of 2 pages

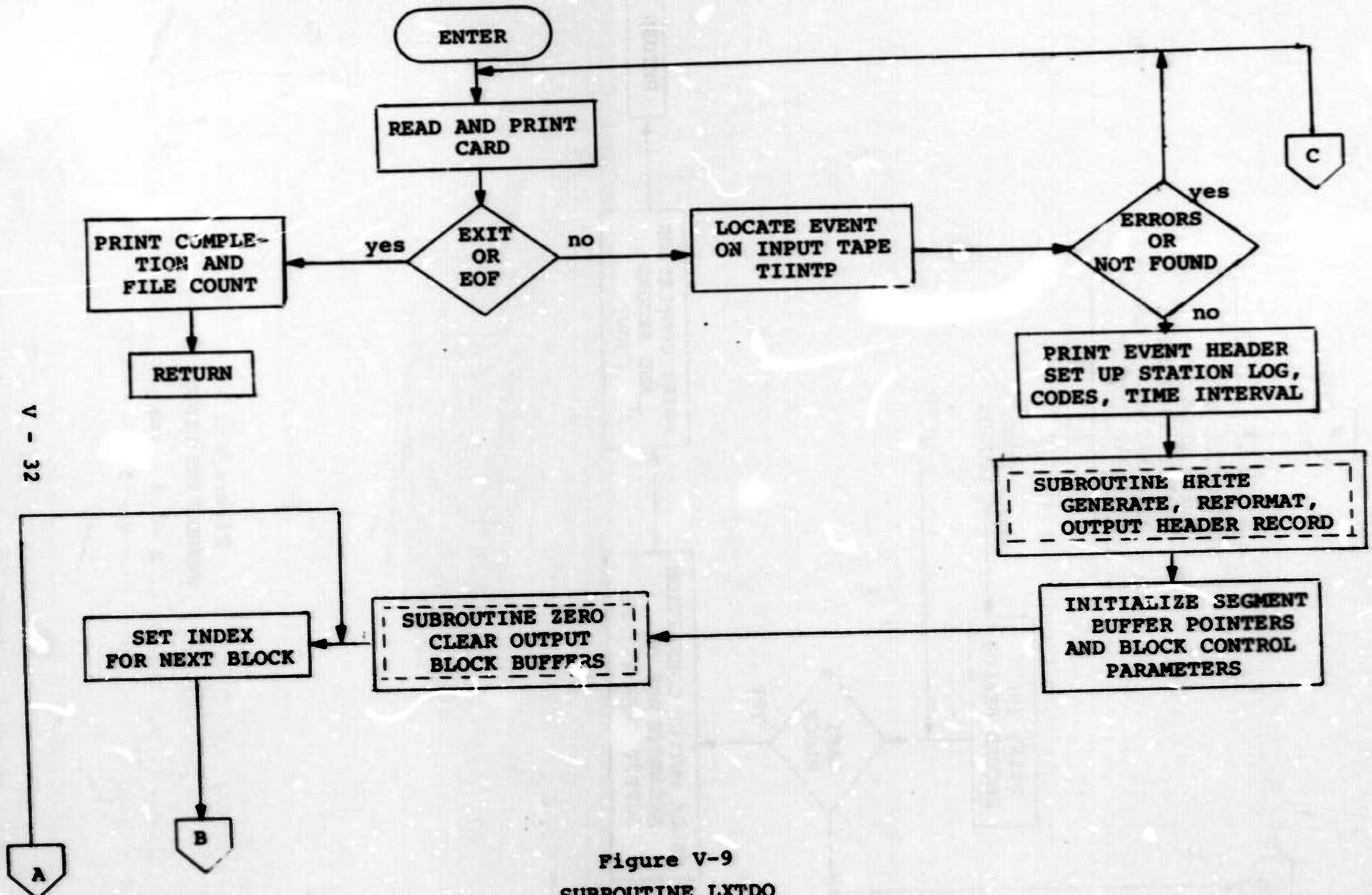


Figure V-9
SUBROUTINE LXTDO
1 of 2 pages

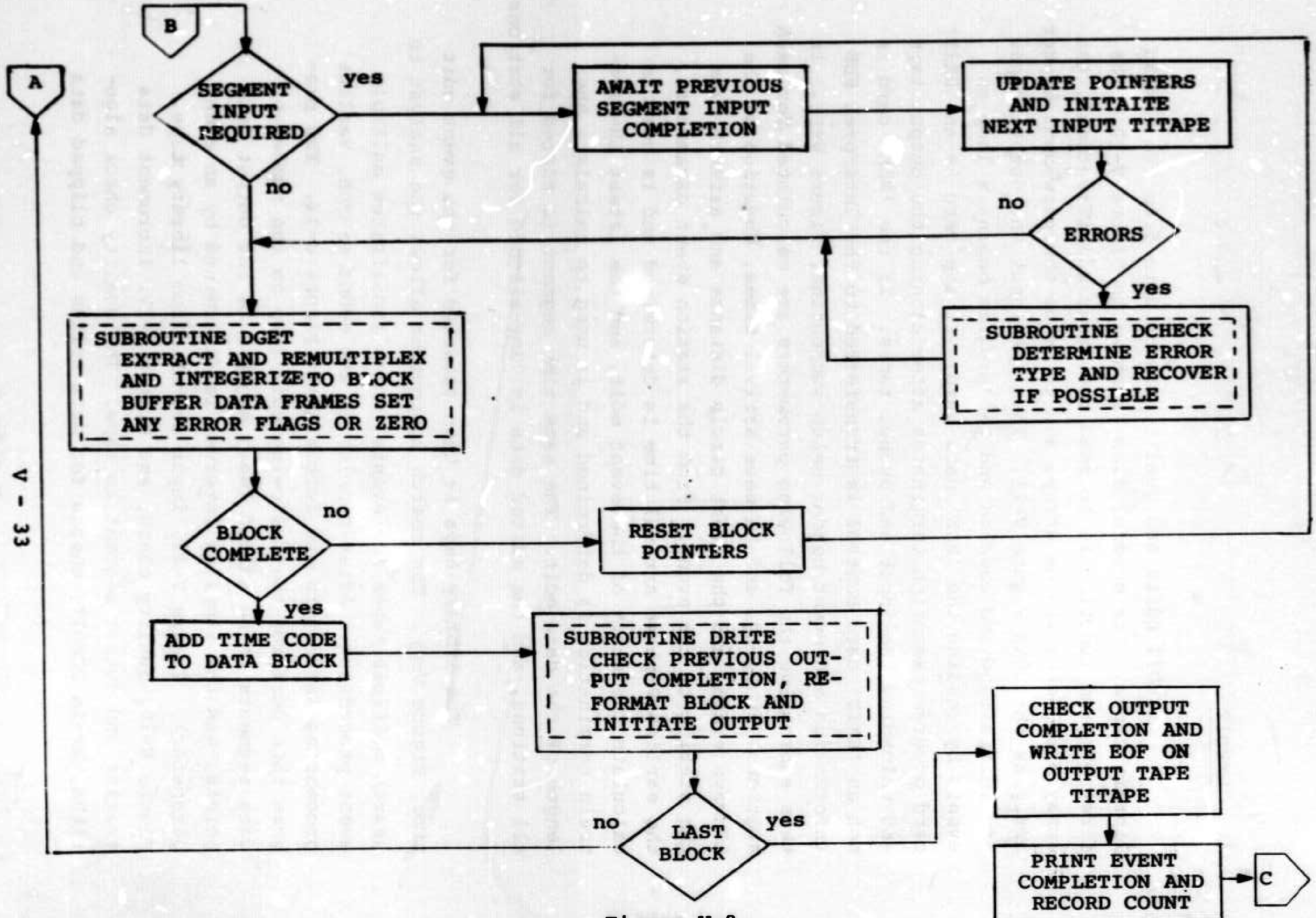


Figure V-9
SUBROUTINE LXTDO
2 of 2 pages

4. LXEDIT

LXEDIT edits and quality checks data from the LXMERG library tapes. Its general flow is shown in Figure V-10. The first program function is to read the array specifications, the array processing status array, and to setup the permanent header array as shown in Figure V-11. Then the input and output tapes are initialized and checked and the program begins a loop on events by reading the 'PDE' data card. If the card is an 'EXIT' card program execution terminates after closing the output tape and unloading the input and output tapes. If the 'PDE' card is not an 'EXIT' card control is transferred to the interpret PDE information and event header setup subroutine, Figure V-12. In this subroutine the following parameters are calculated for each station: P, S, LQ, and LR wave arrival times, duration of the LR wave train, and the great circle distance and azimuth from the station to the event. From the station event parameters, the earlist P-phase arrival time is determined and is used to calculate the start of the event edit, and the latest LR-wave-train termination is determined and is used to calculate the length of the data edit. The same time segment is edited for all stations, and the edited data is time-aligned for all stations.

The library tape is then searched for the event edit time, Figure V-13. The search subroutine allows the analyst to search multiple tapes for events, which facilitates multiple event processing. After completing the event search, various processing parameters are initialized, Figure V-14. The program then performs the following edit loop on the number of data segments to be edited (each segment is 128 output data points, and the sampling interval is determined by an event parameter): Figure V-15, input segment from library tape, Figure V-16, quality check, and Figure V-17, increment data trailer and output segment to tape. The quality check algorithm, as in QCEDIT, checks for data spikes and clipped data

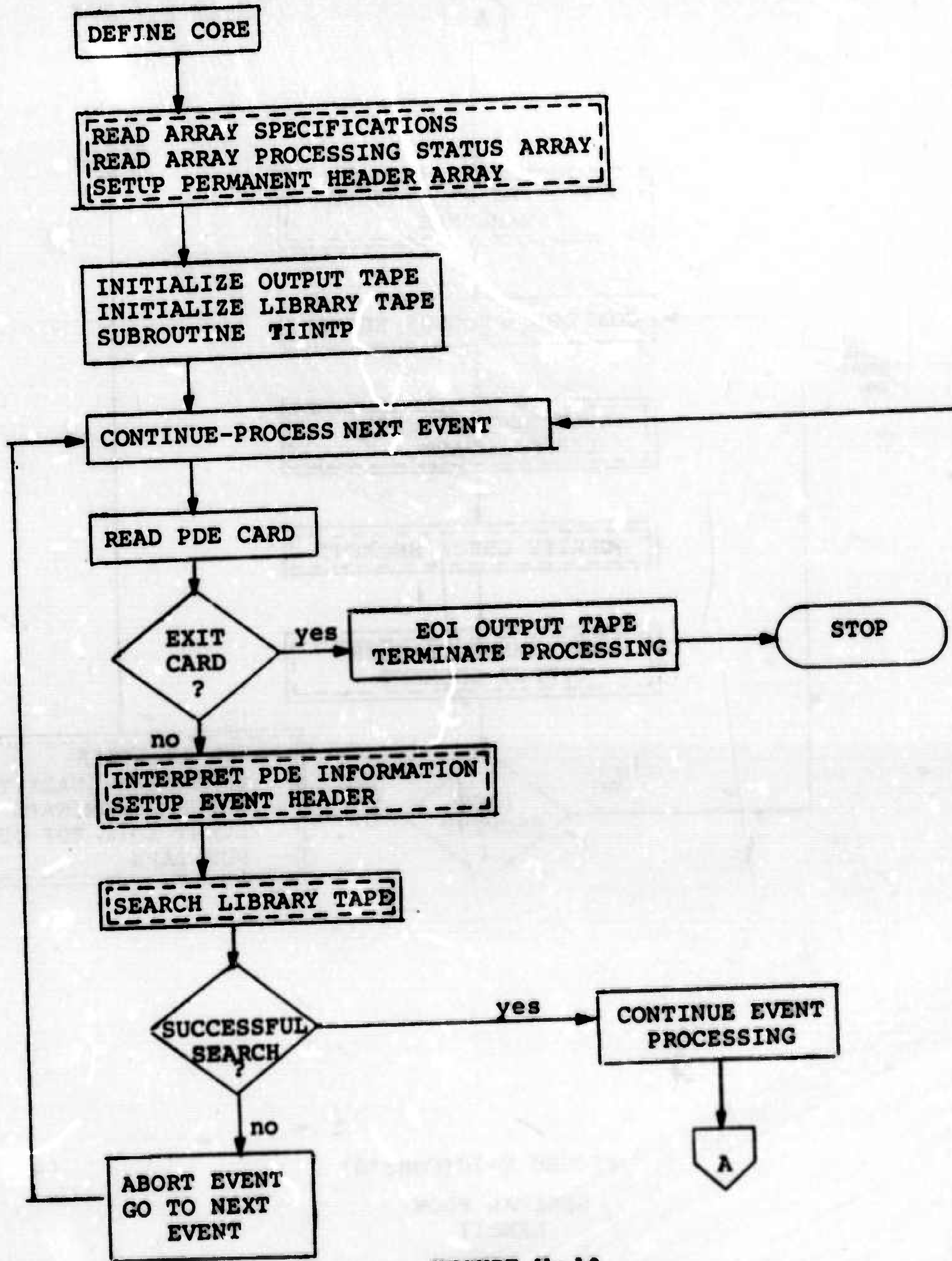


FIGURE V- 10

GENERAL FLOW
LXEDIT

PAGE 1 OF 2 PAGES

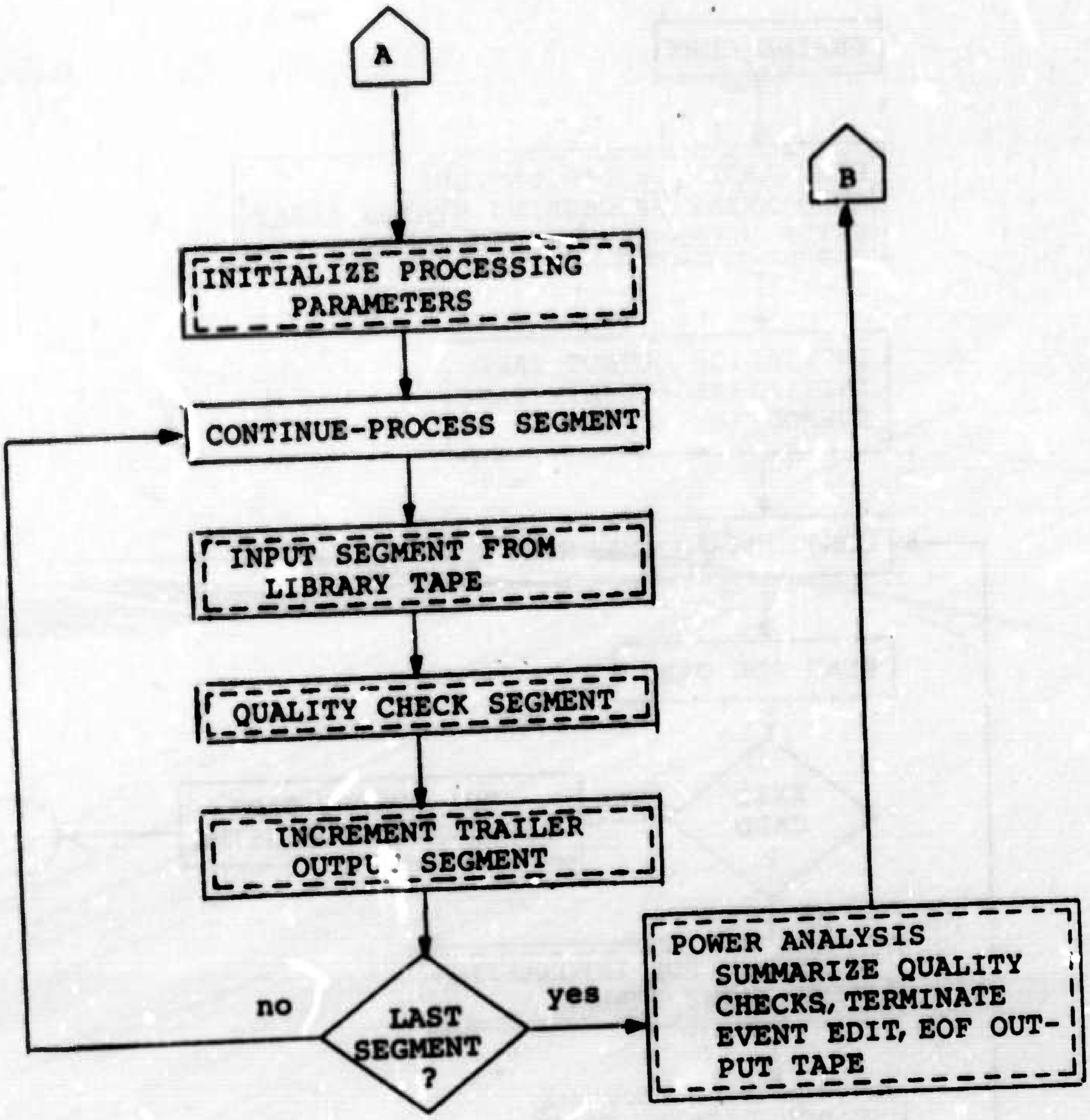


FIGURE V-10 (Cont'd)

GENERAL FLOW
LXEDIT

PAGE 2 OF 2 PAGES

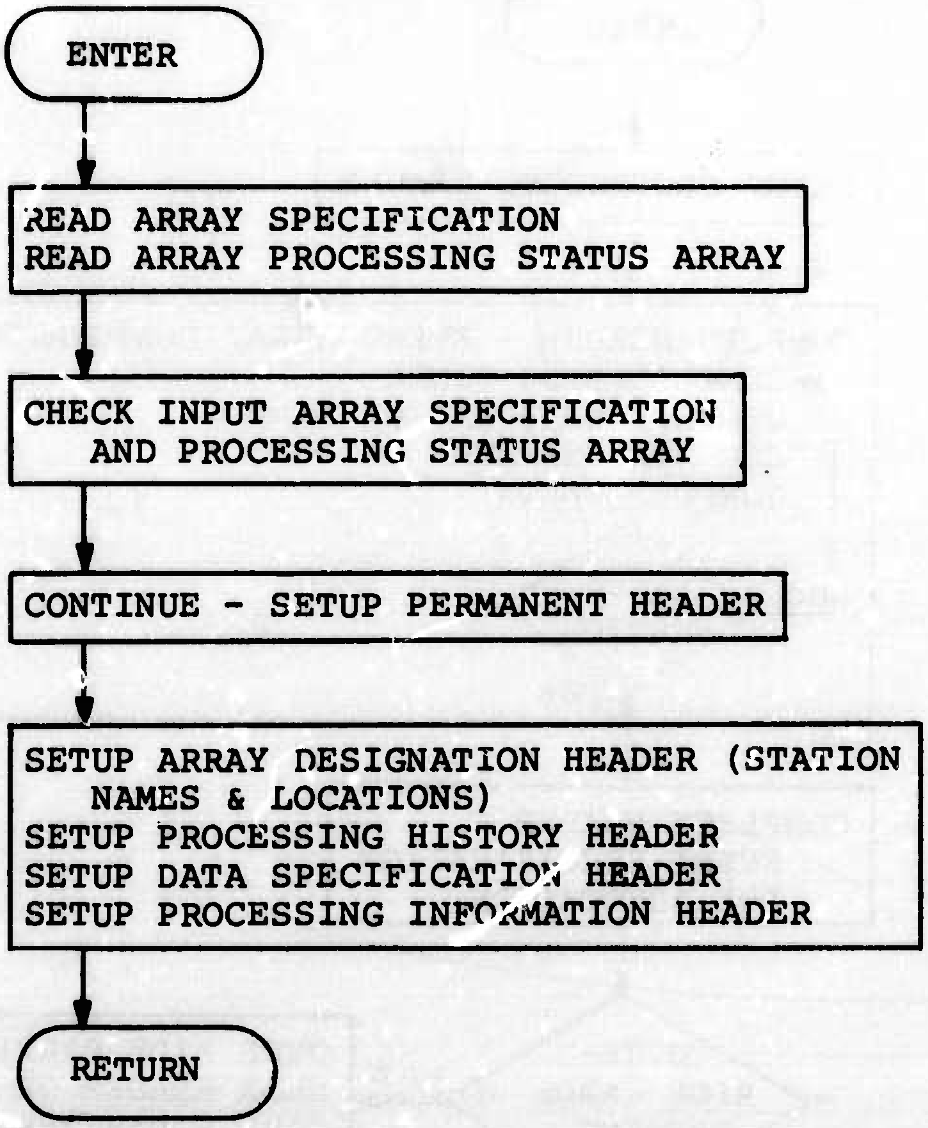


Figure V-11
SUBROUTINE LXEDIT 1

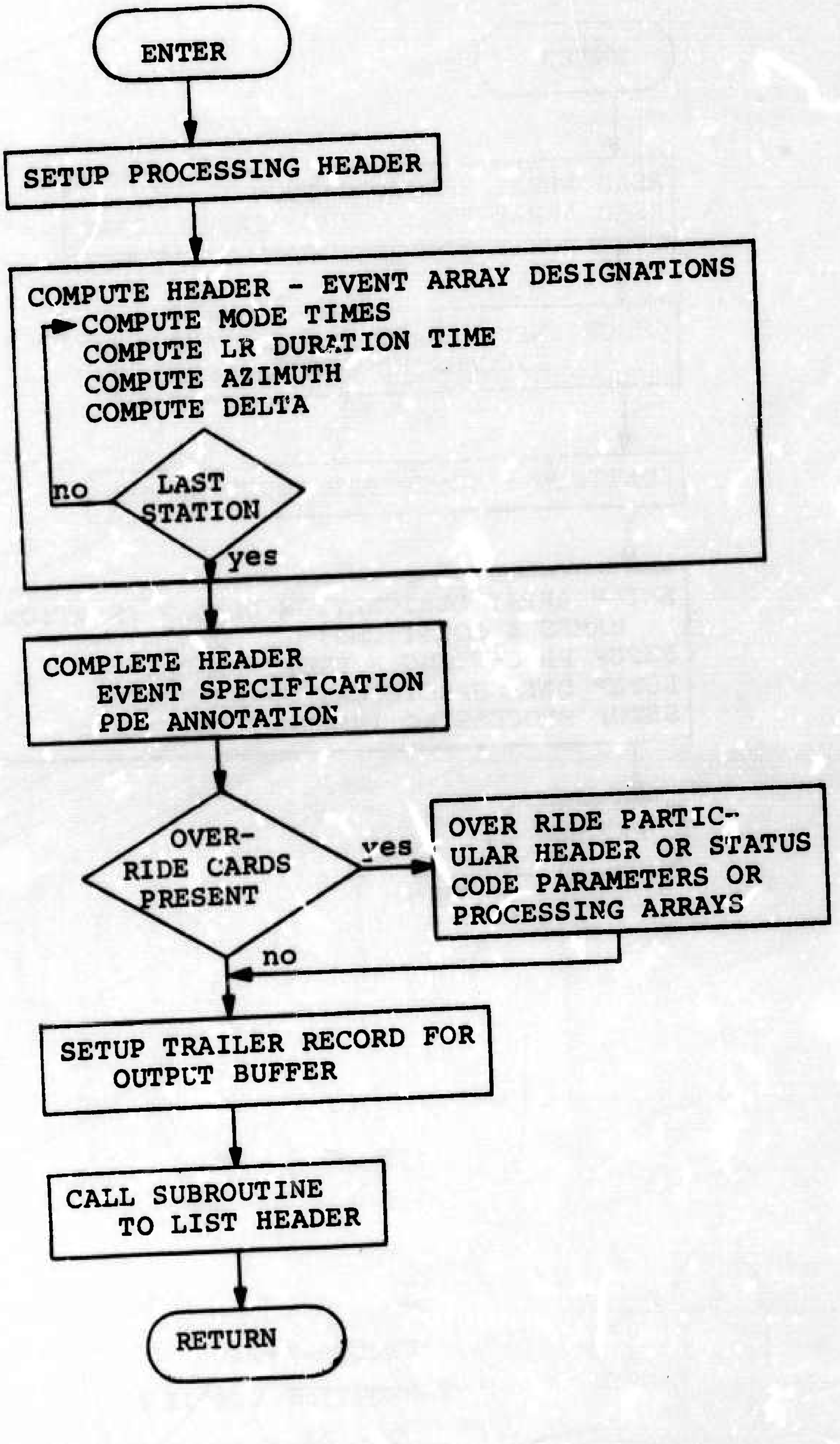


Figure V-12
SUBROUTINE LXEDIT 2

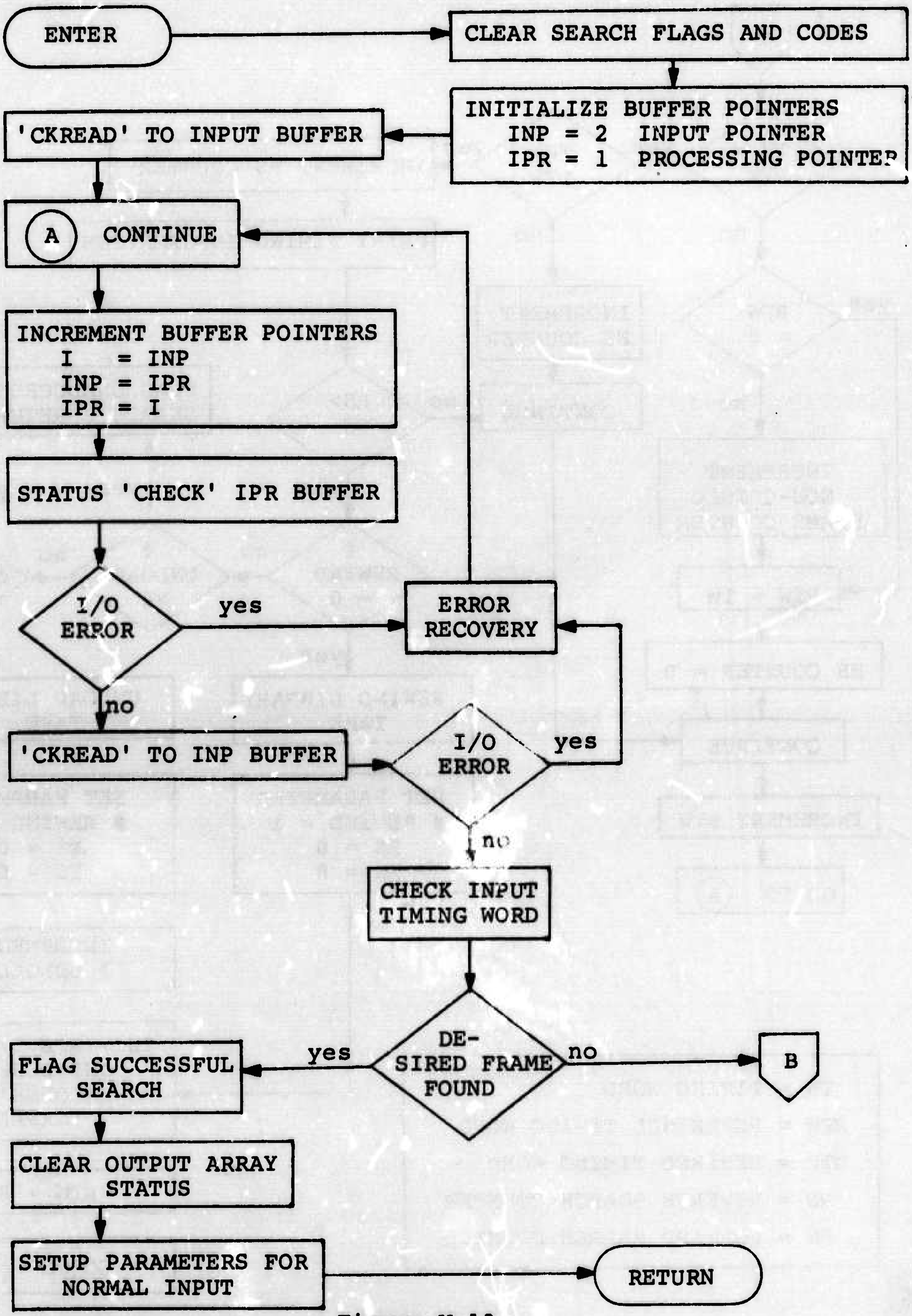


Figure V-13

SUBROUTINE LXEDIT 3

1 of 2 pages

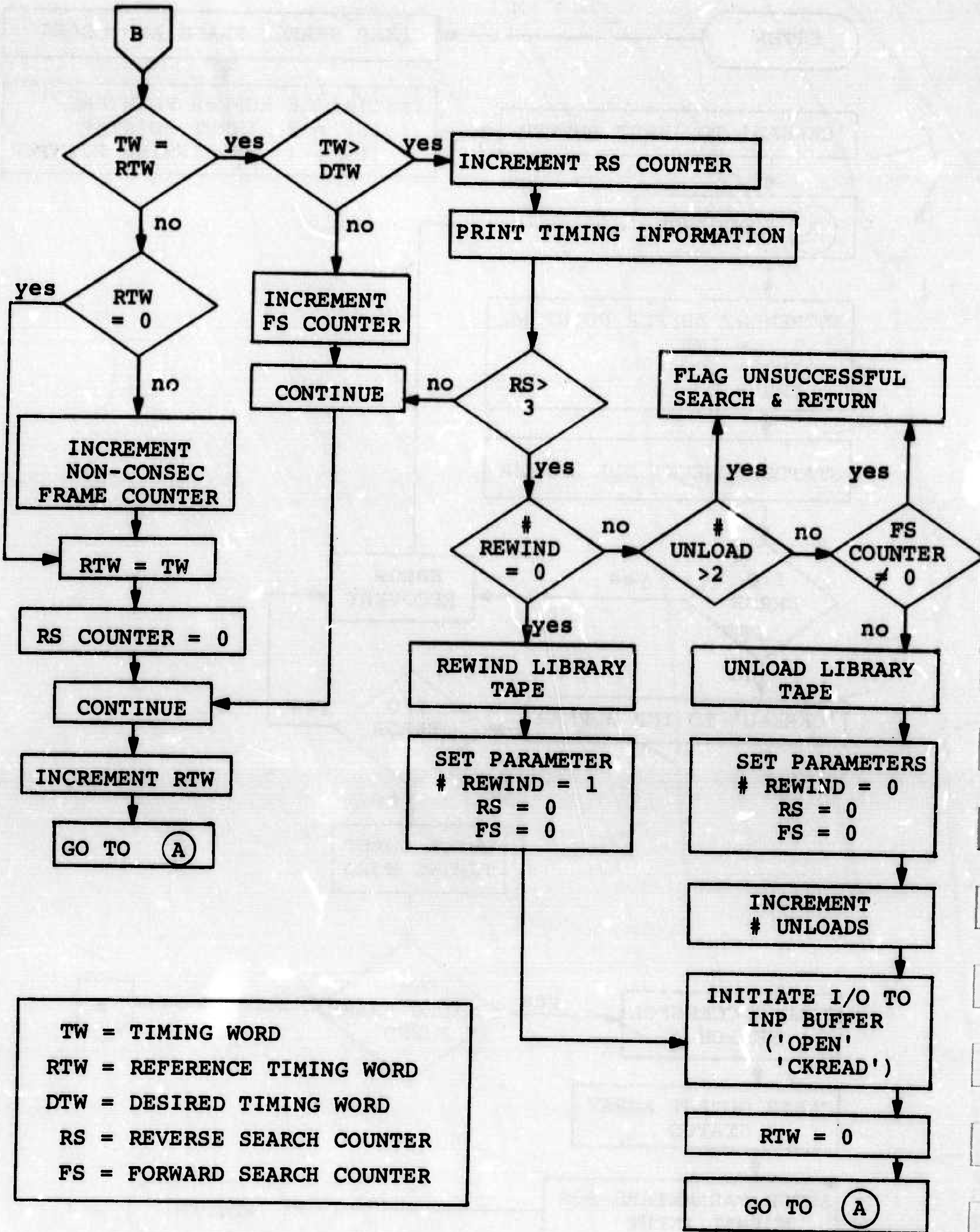


Figure V-13
SUBROUTINE LXEDIT 3
2 of 2 pages

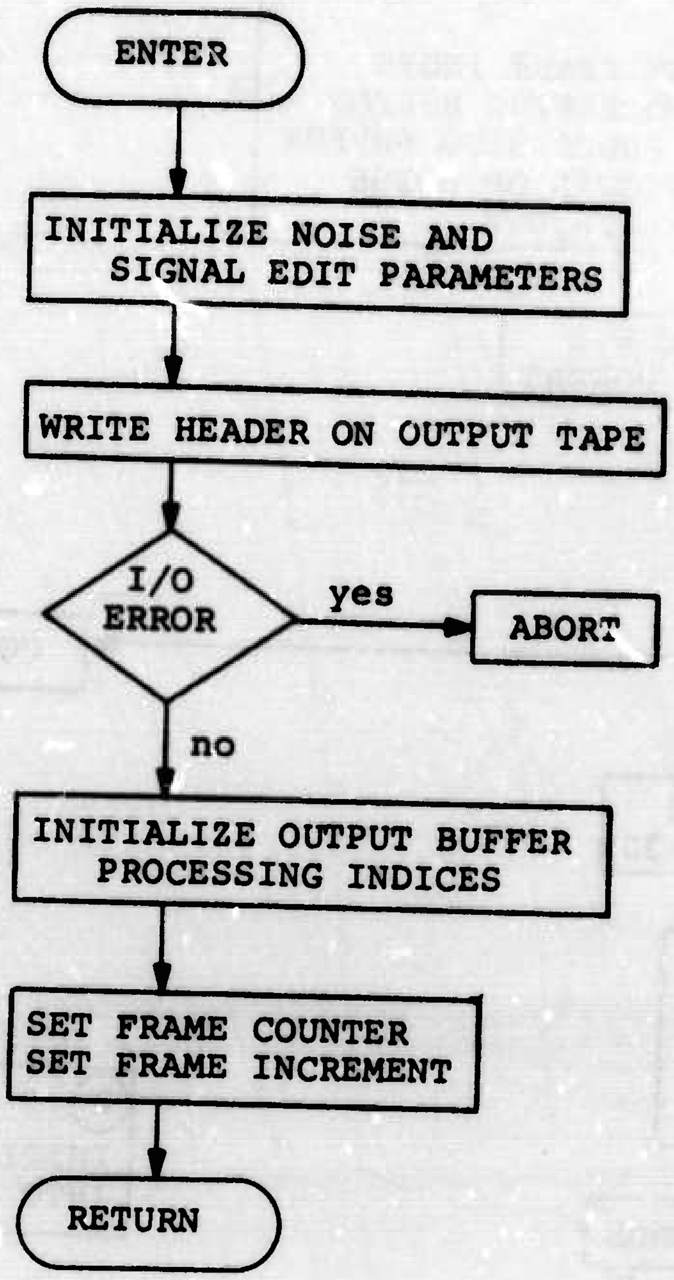


Figure V-14

SUBROUTINE LXEDIT 4

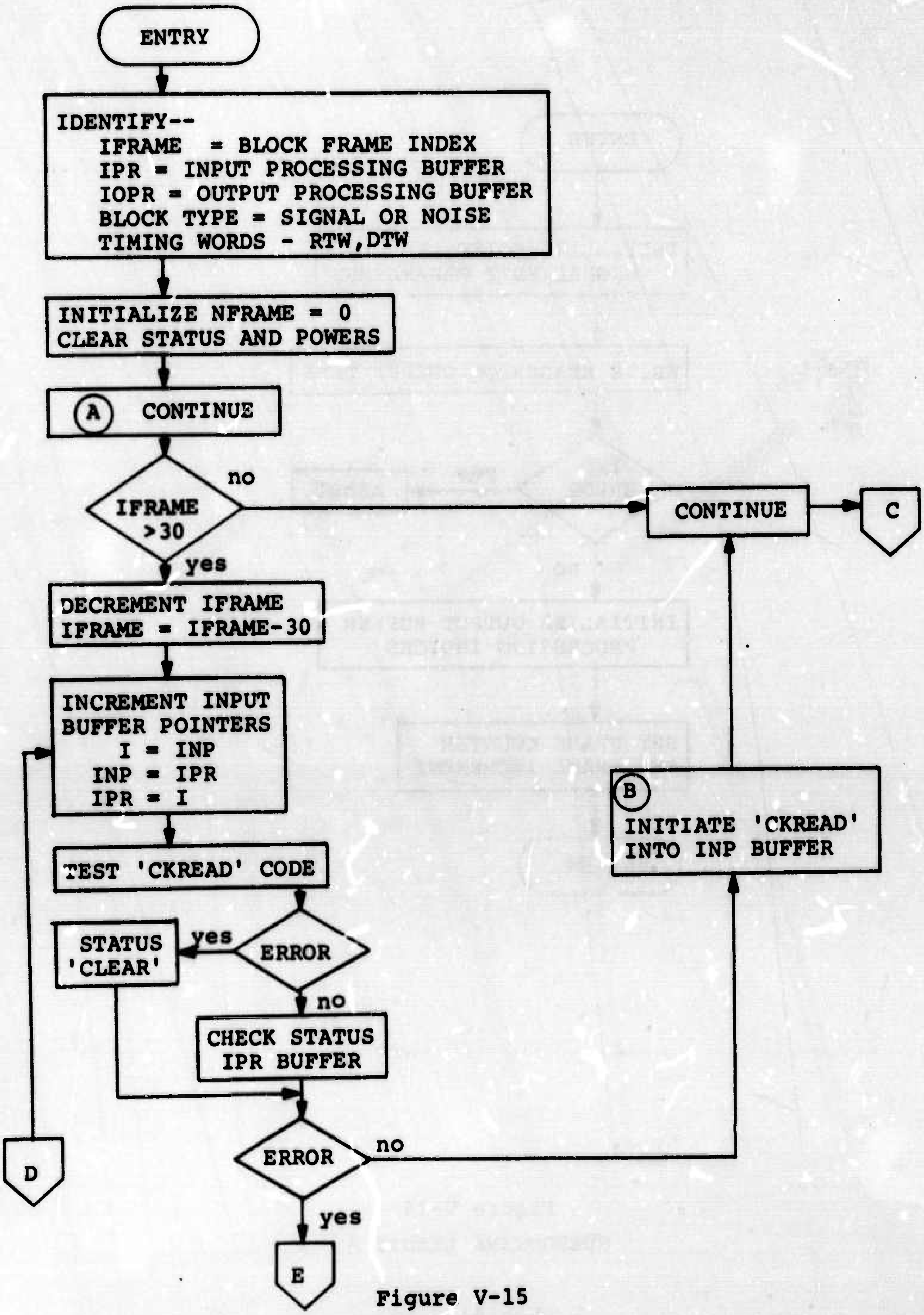


Figure V-15
SUBROUTINE LXEDIT 5
1 of 3 pages

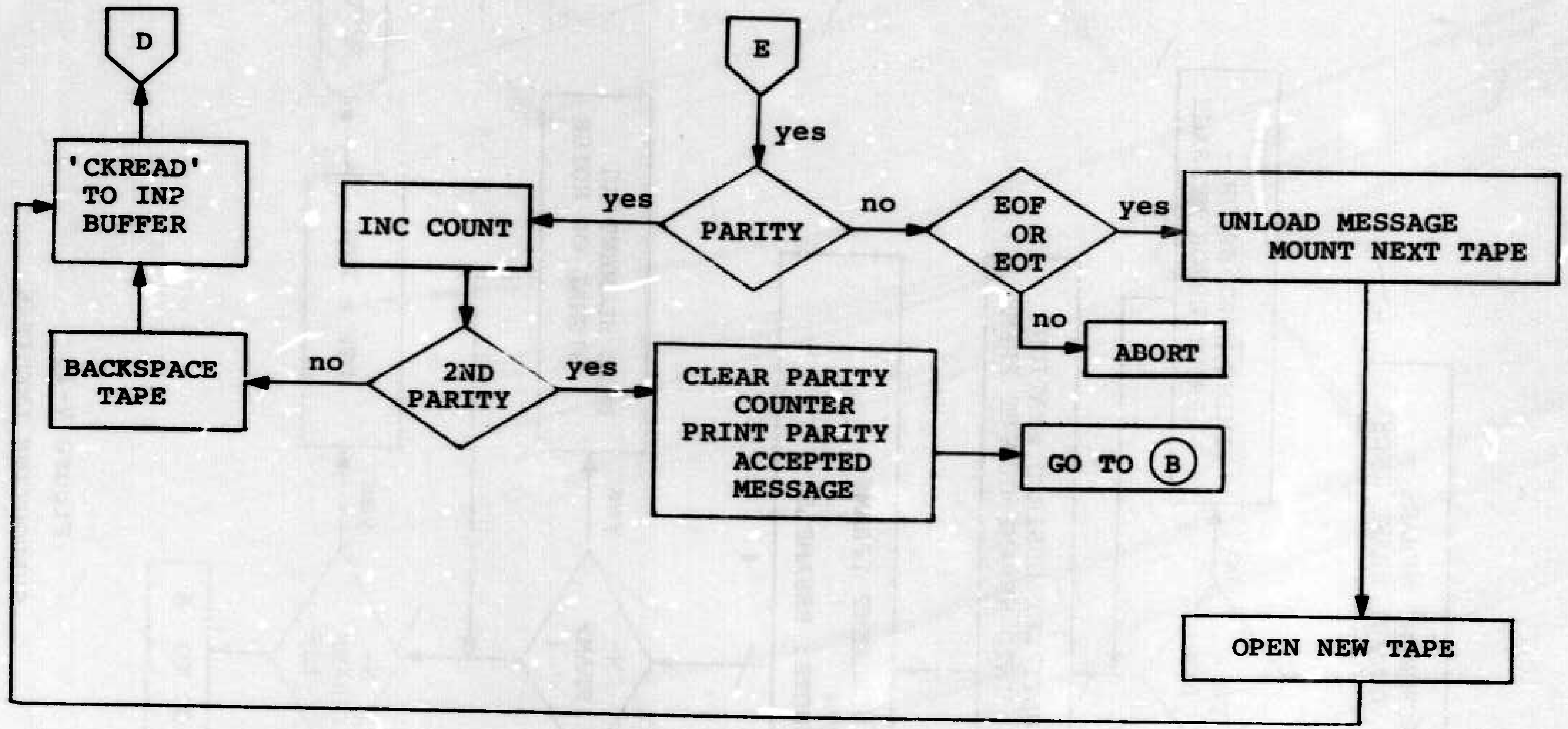


Figure V-15
SUBROUTINE LXEDIT 5
2 of 3 pages

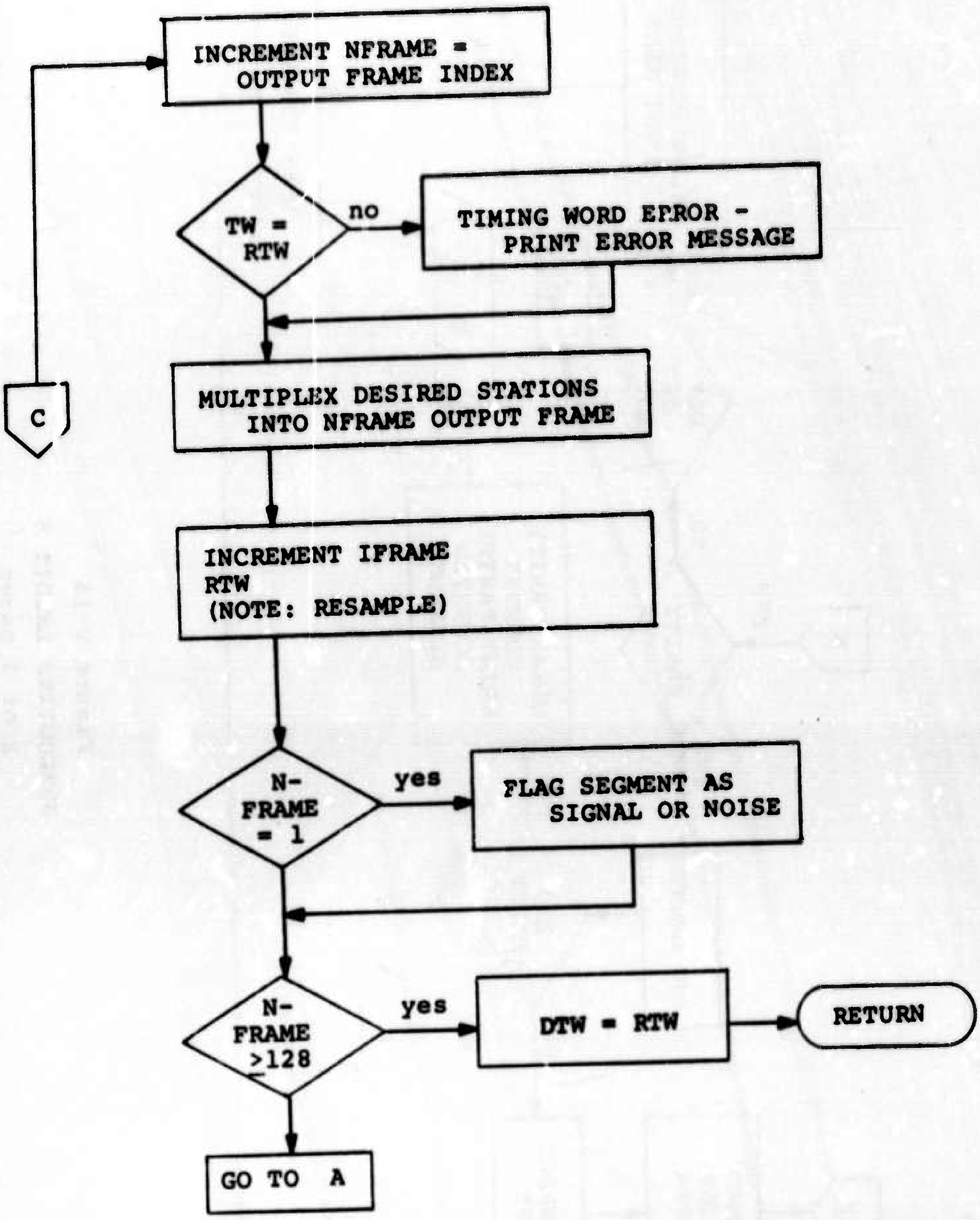


Figure V-15
SUBROUTINE LXEDIT 5
3 of 3 pages

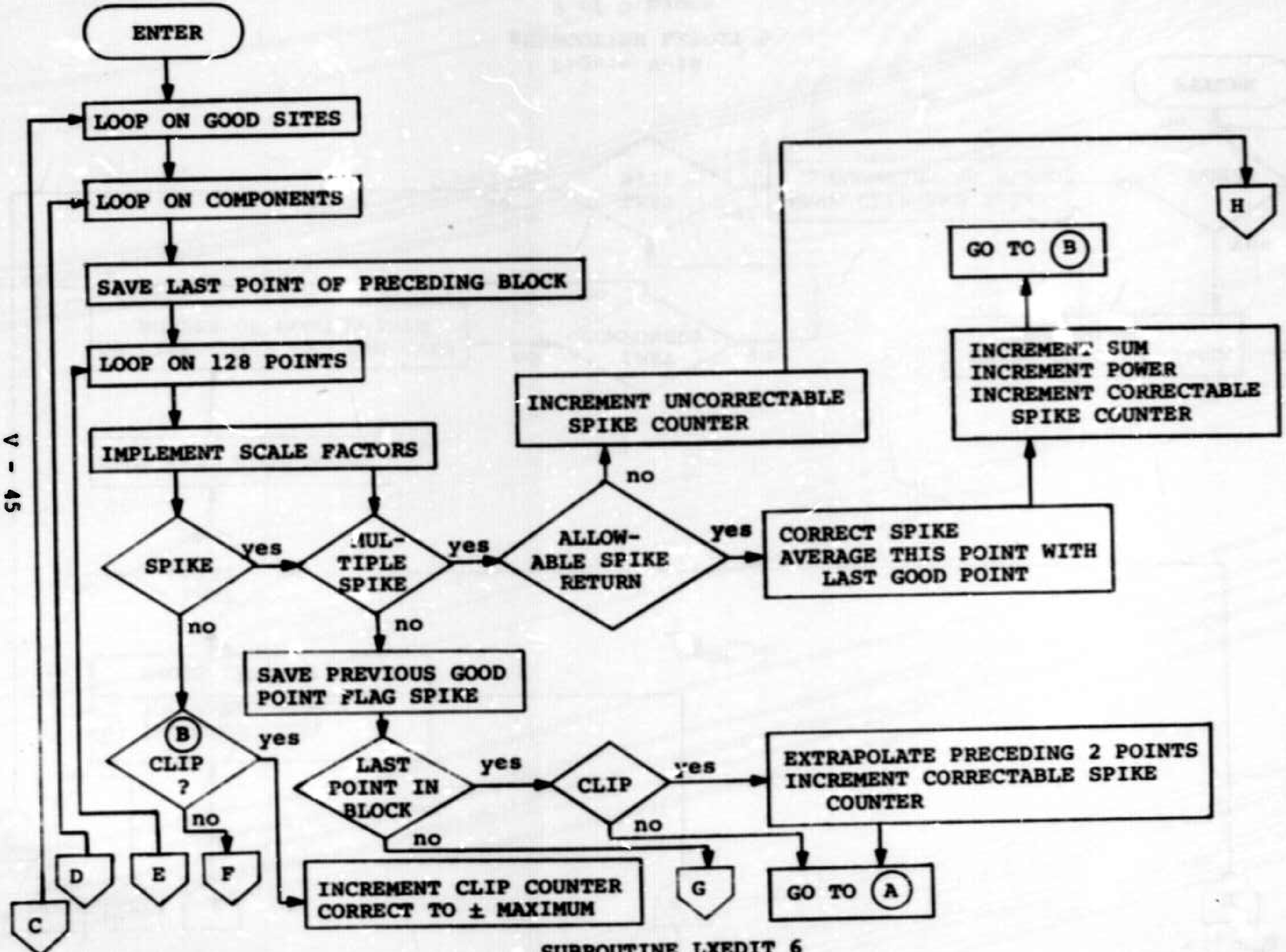


Figure V-16

SUBROUTINE LXEDIT 6

1 of 2 pages

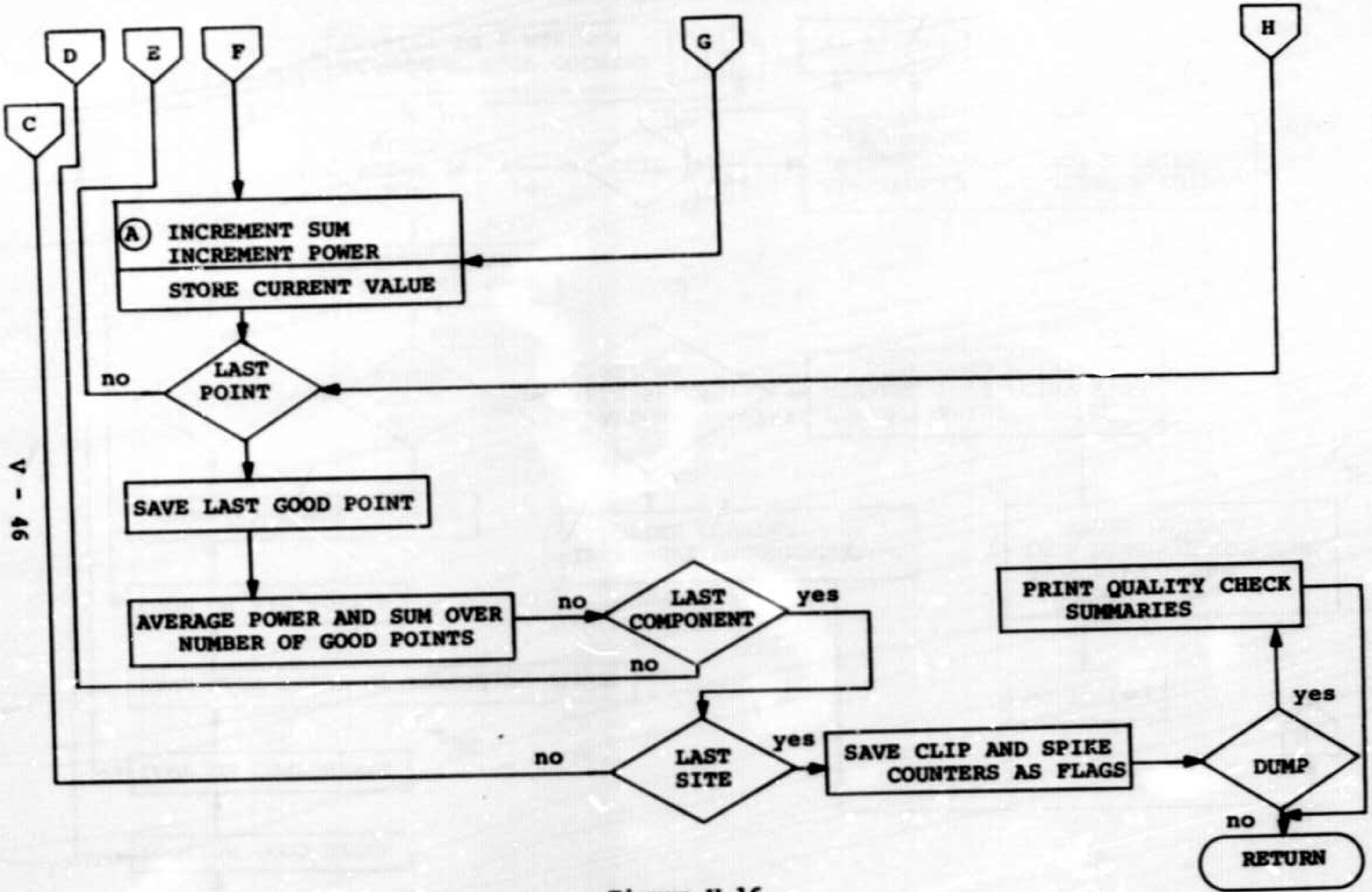


Figure V-16
SUBROUTINE LXEDIT 6
2 of 2 pages

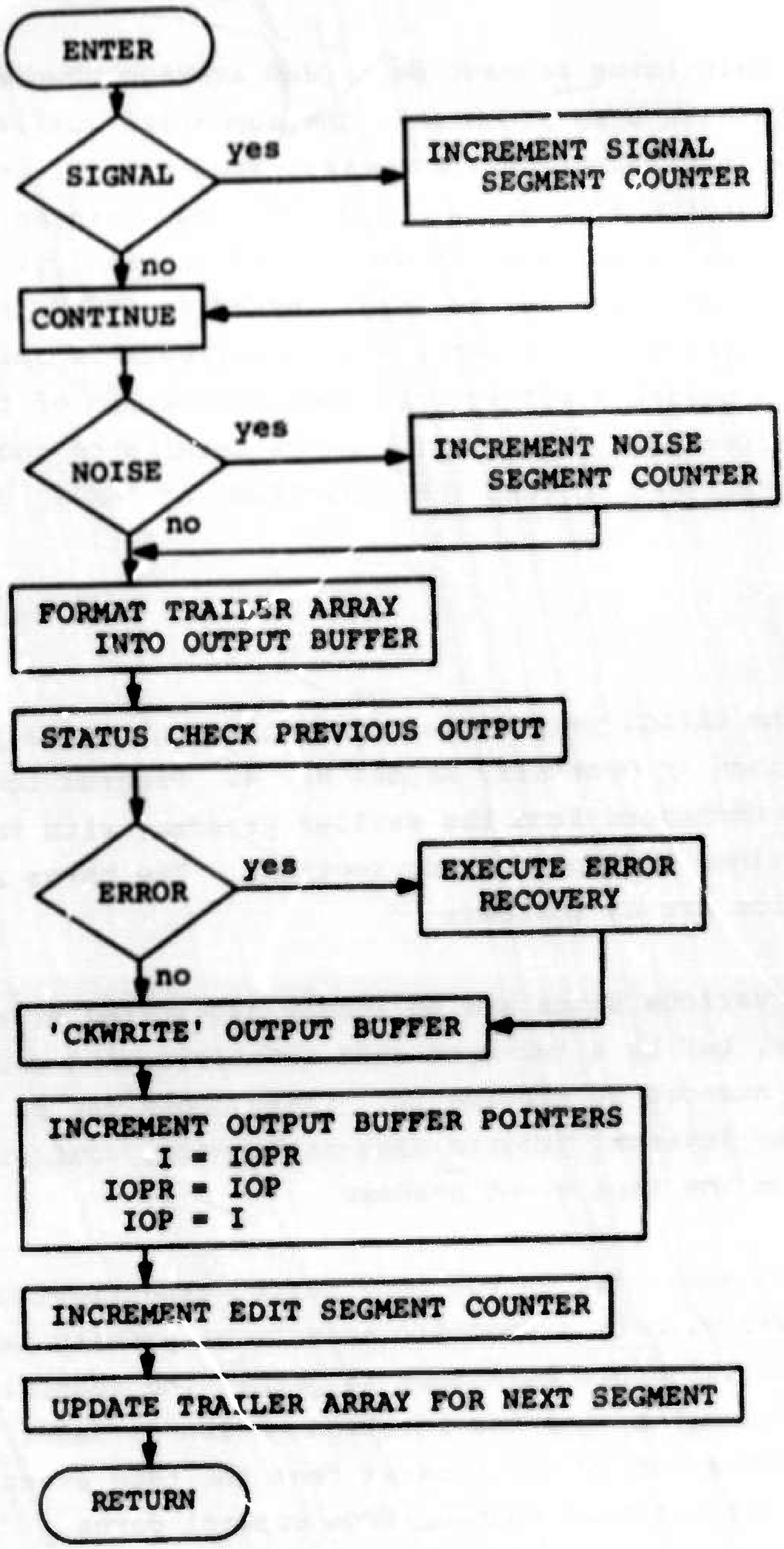


Figure V-17
SUBROUTINE LXEDIT 7

points and calculates segment means and average powers. After all segments have been processed, the summarize quality checks and event edit termination subroutine, Figure V-18, is called. In this subroutine site means are calculated, printed, and punched for use in program LXGEN. To aid the analyst in choosing which segments are not to be processed in LXGEN, segment powers are printed and segments with uncorrectable spikes and/or clipped data points are flagged. Upon completion of the quality check summarizations, the event tape is terminated and program control is returned to read the next 'PDE' or 'EXIT' card.

5. LXPLOT

The LXPLOT program is a modification of the program EVPLOT described in Quarterly Report No. 4. Program logic and flow are unchanged from the earlier program, with the modification confined to input/output sections. The three areas of modification are as follows:

1. The various sites are no longer designated by an index integer, but by a two-byte site identification code which may be numeric or alphabetic. These codes may be initialized either by internal program data statements, control card input, or from the tape event headers.

2. Since each site in the long period experiment will have associated with it a specific azimuth or primary beam direction, provision has been made to permit the specification of different azimuths when the rotation option is used. These azimuths are obtained by the program from the tape event headers or with a minor software change, from control cards.

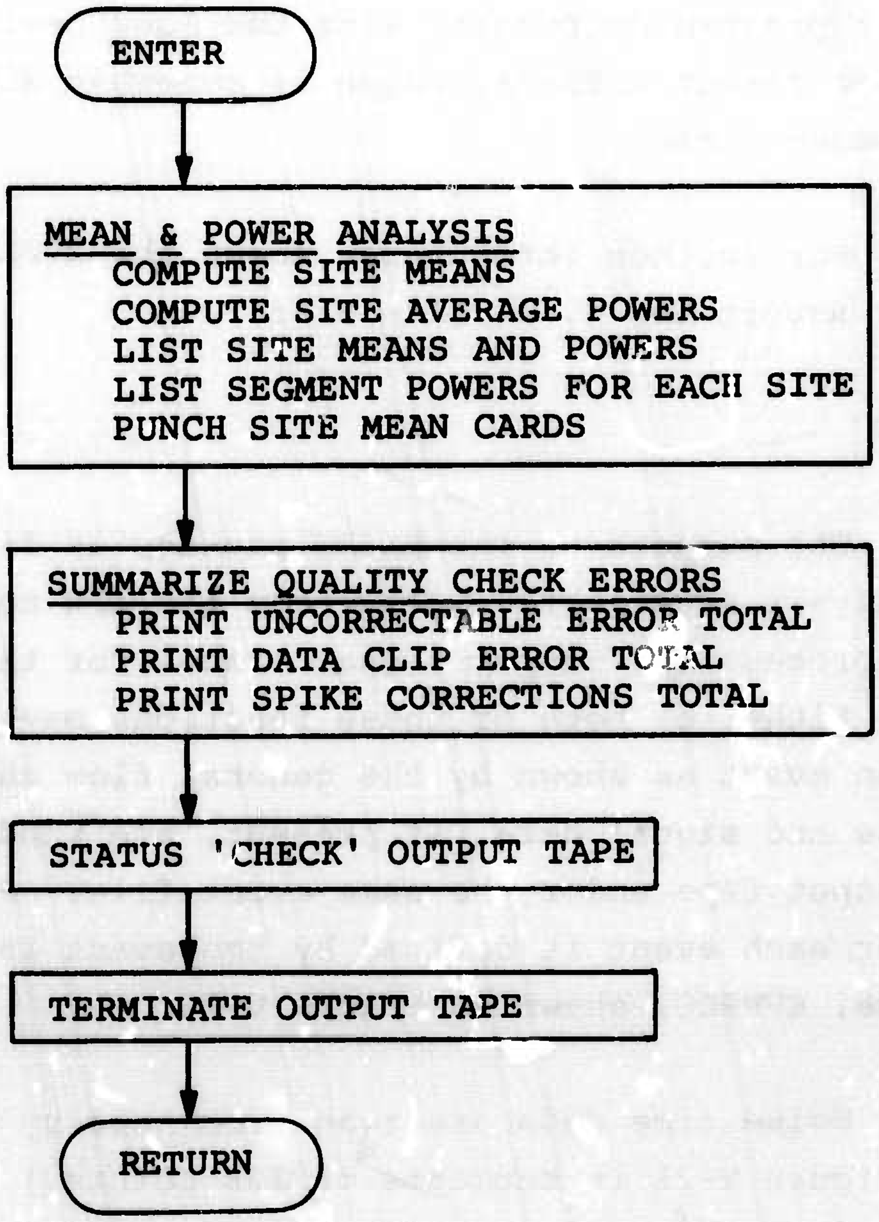


Figure V-18

SUBROUTINE LXEDIT 8

3. Finally, a number of internal changes have been made in the parameter initialization section of the subroutine PROCES to provide program conformity with the long period experiment data header format LXTDATA, which is somewhat altered from the TDDATA header format.

For further information about the EVPLOT program, see Quarterly Report No. 4, p. III-58 ff.

6. LXGEN

The purpose of the LXGEN package is first to perform noise analysis at selected sites from the LPE network and secondly to process the output signal traces for the trace analysis program. Either or both of these functions may be performed on a given event as shown by the general flow chart in Figure V-19. Both noise and signal data, if present, are input from an LXEDIT output tape under the same event file. Processing information for each event is defined by the event initialization subroutine, EVPROC, shown in Figure V-20.

Noise time data are read from tape by subroutine INTIME (Figure V-21 in segments of 128 points.) Data from selected sites are then placed in a buffer either one or two segments at a time and transformed as shown by the flowchart of subroutine TRANSF, Figure V-22. After bandpassing, the transforms may be rotated to the primary beam direction for each site, if desired. A three-component crosspower spectral matrix is generated for each selected site and accumulated over all processed segments. The flowchart of the matrix accumulation routine ACMCPS is given in Figure V-23.

After the completion of the matrix accumulation, each element of the matrix is scaled to ensure power spectral estimates consistent with Parseval's theorem. Printer plots of the

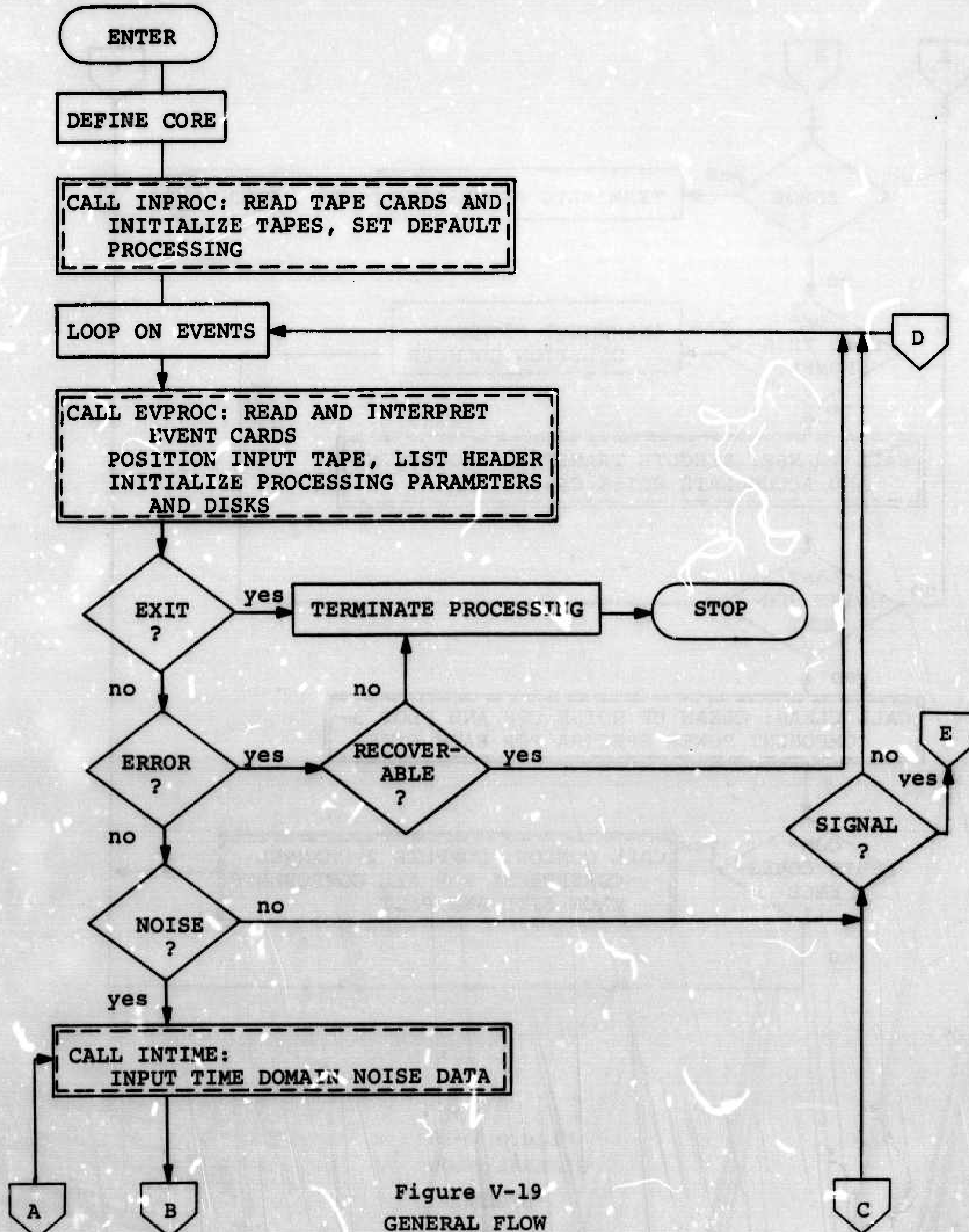


Figure V-19
GENERAL FLOW
LXGEN
1 of 3 pages

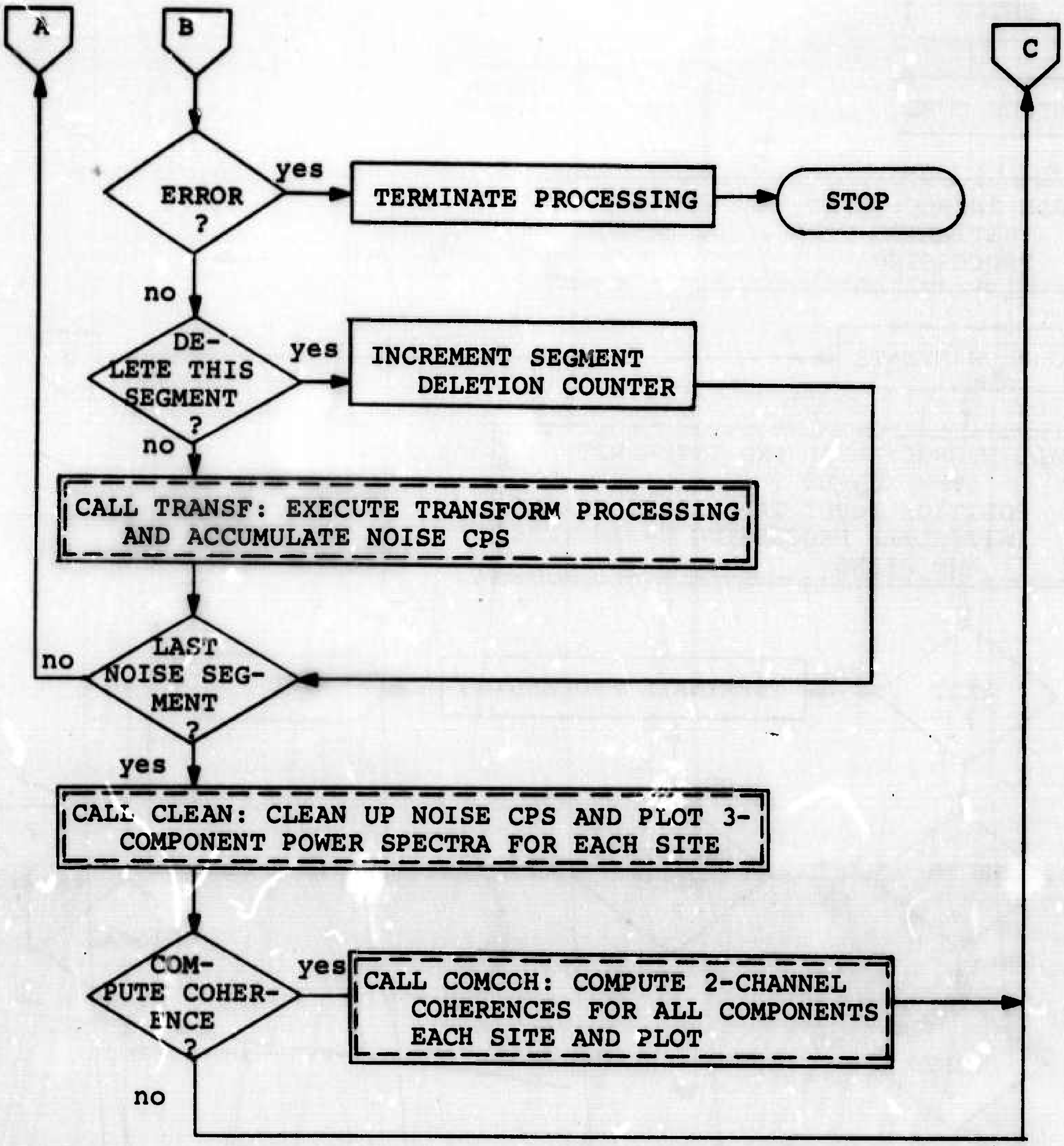


Figure V-19
GENERAL FLOW
LXGEN
2 of 3 pages

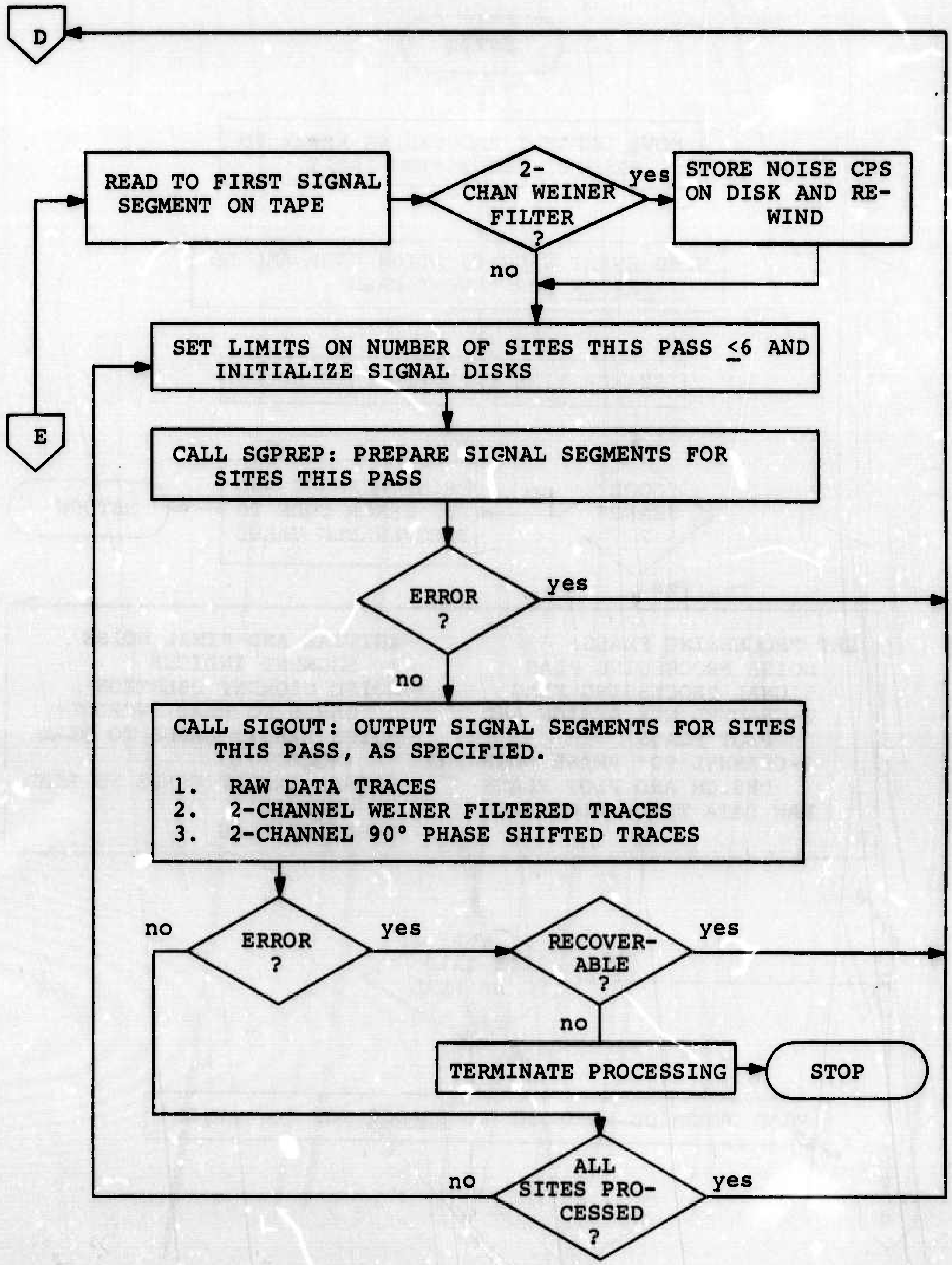


Figure V-19
GENERAL FLOW
LXGEN
3 of 3 pages

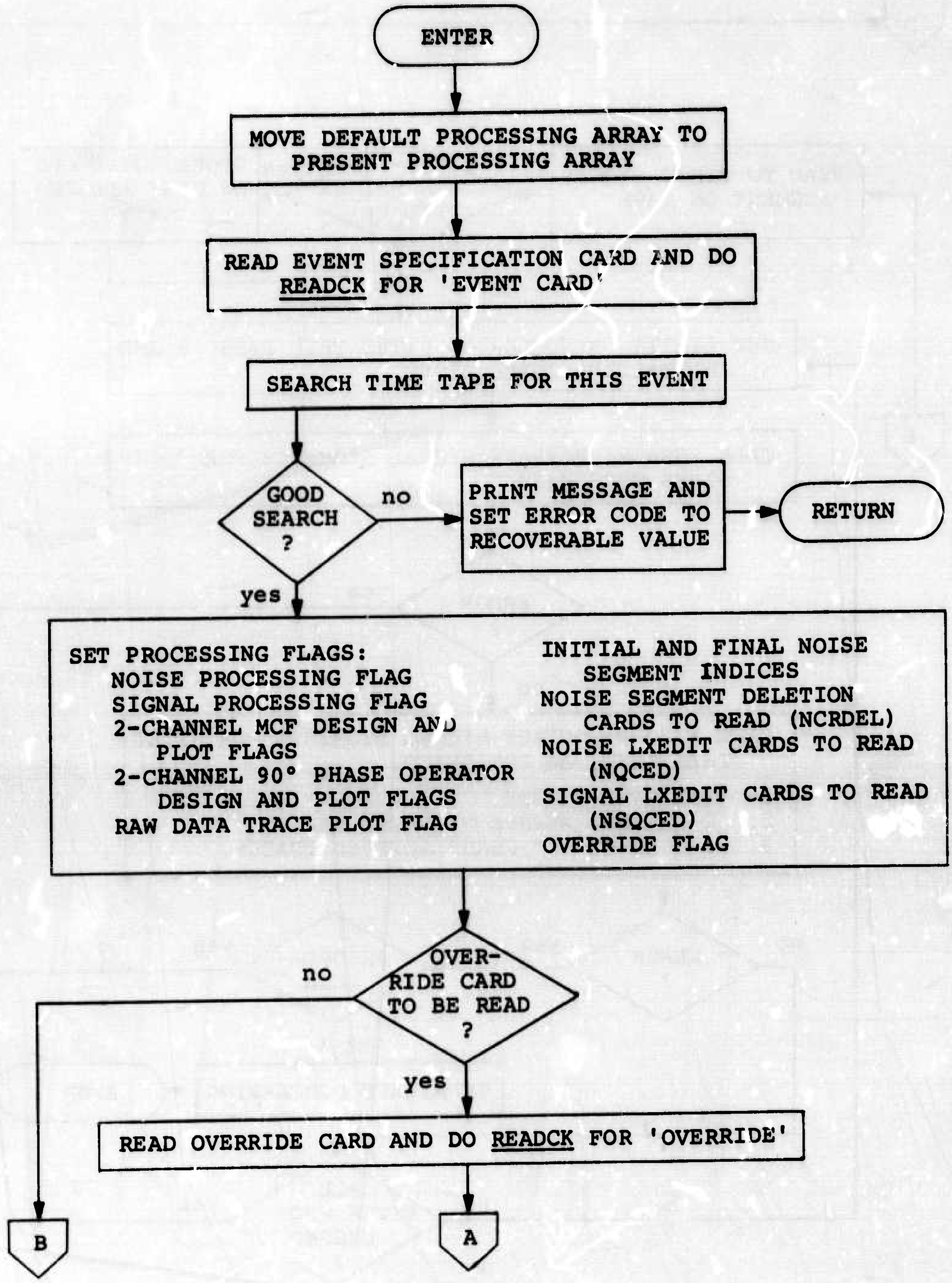


Figure V-20
SUBROUTINE LXPROC
1 of 3 pages

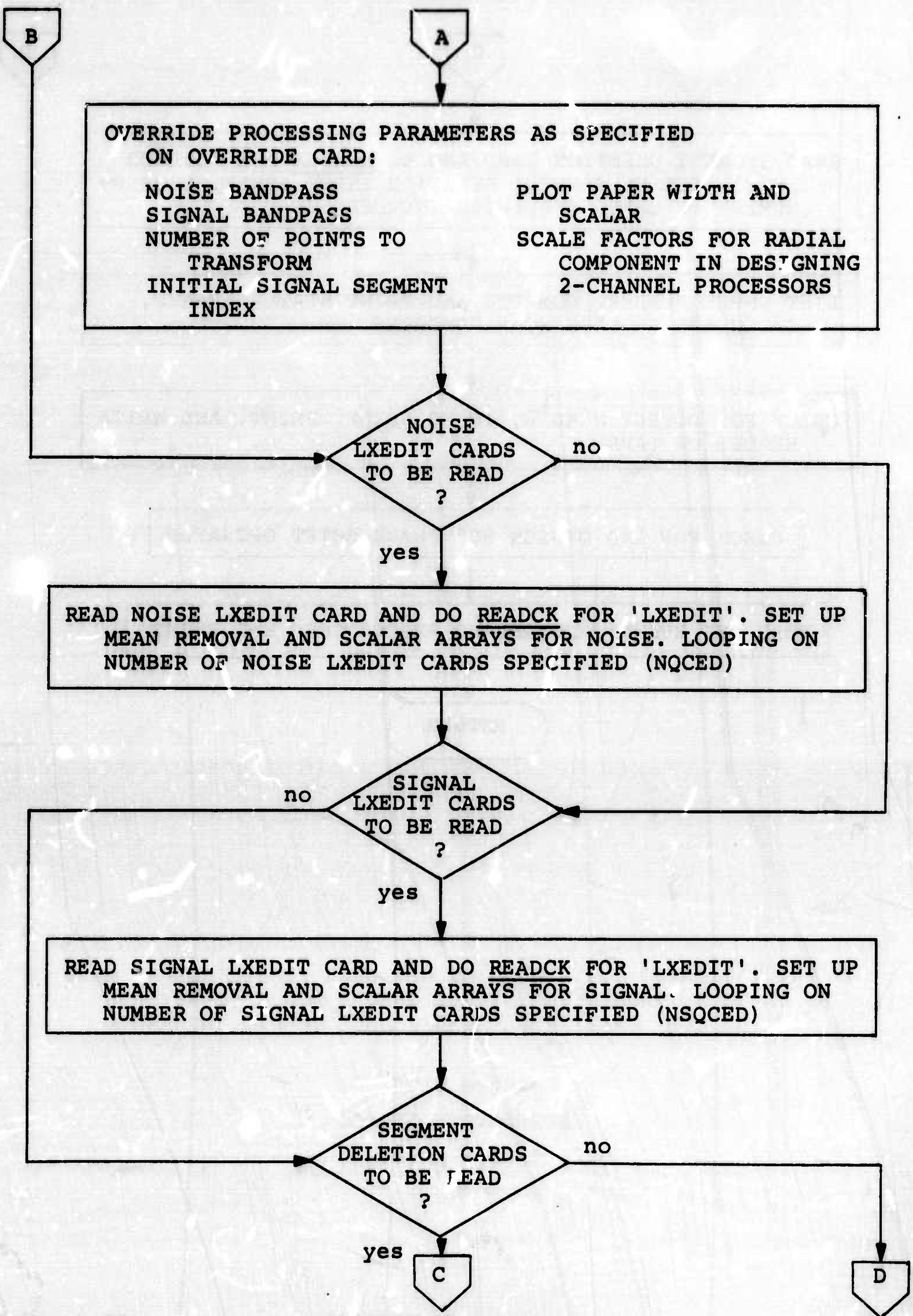


Figure V-20 SUBROUTINE LXPROC
2 of 3 pages

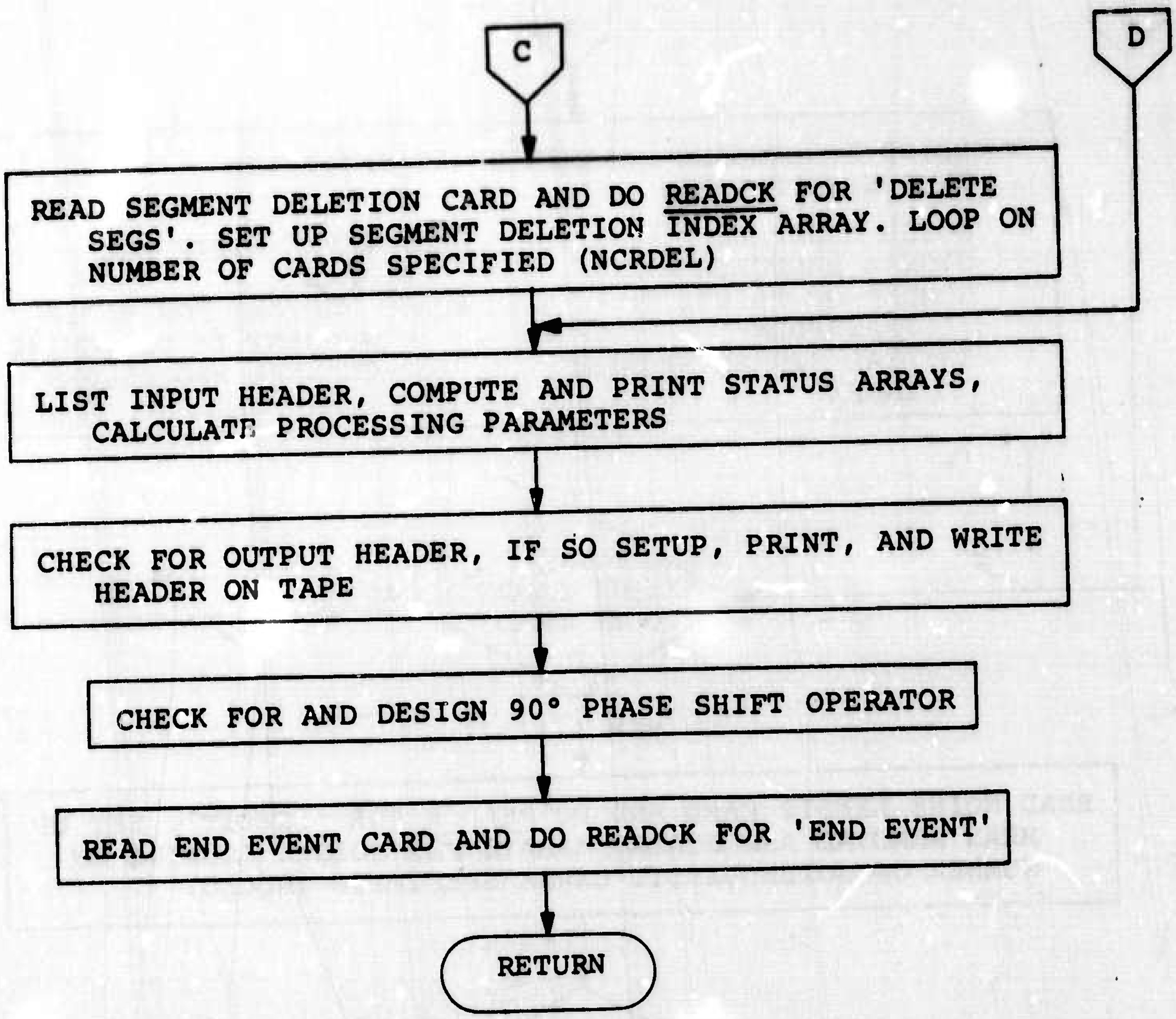


Figure V-20
SUBROUTINE LXPROC
3 of 3 pages

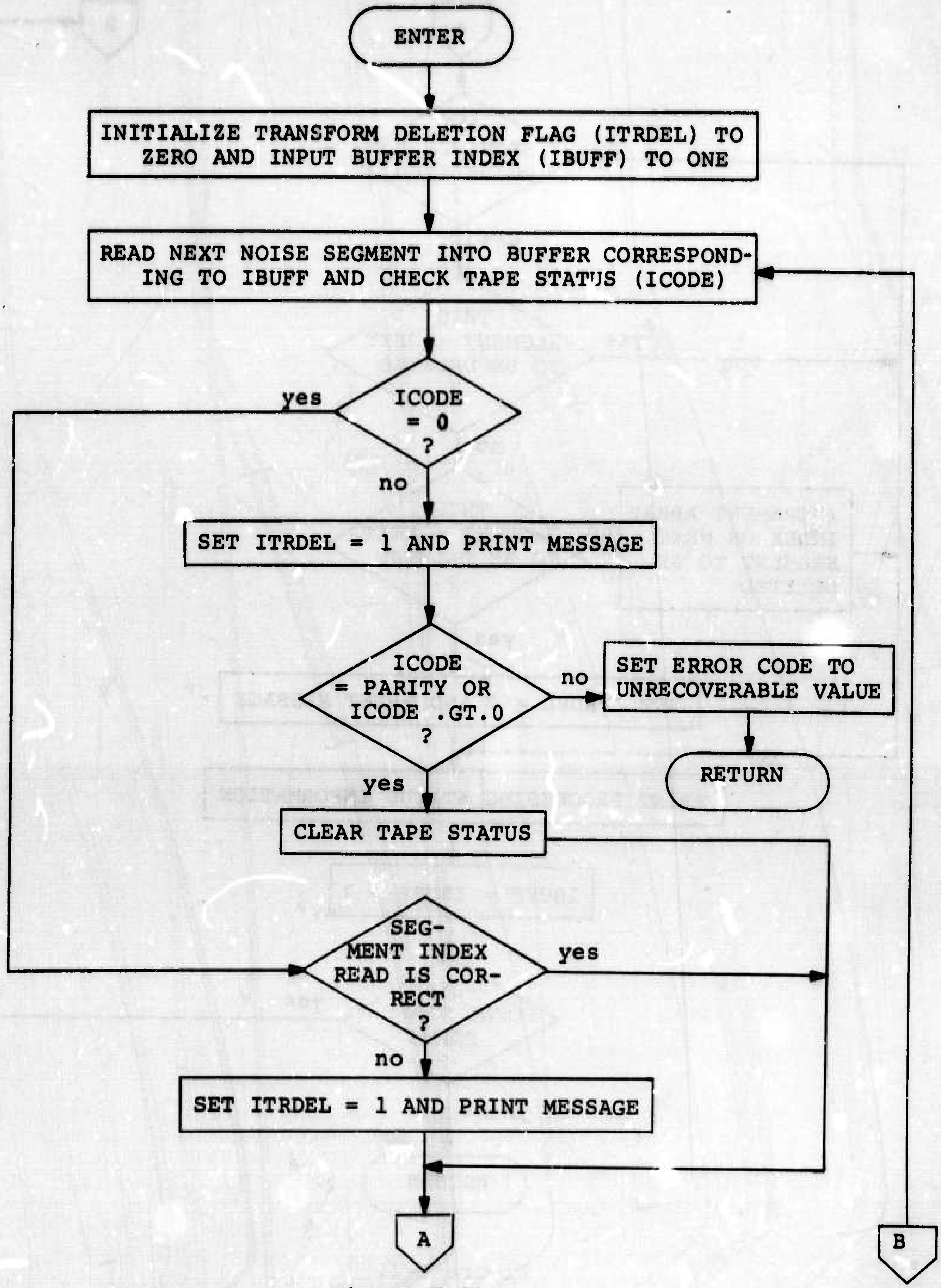


Figure V-21
SUBROUTINE INTIME
1 of 2 pages

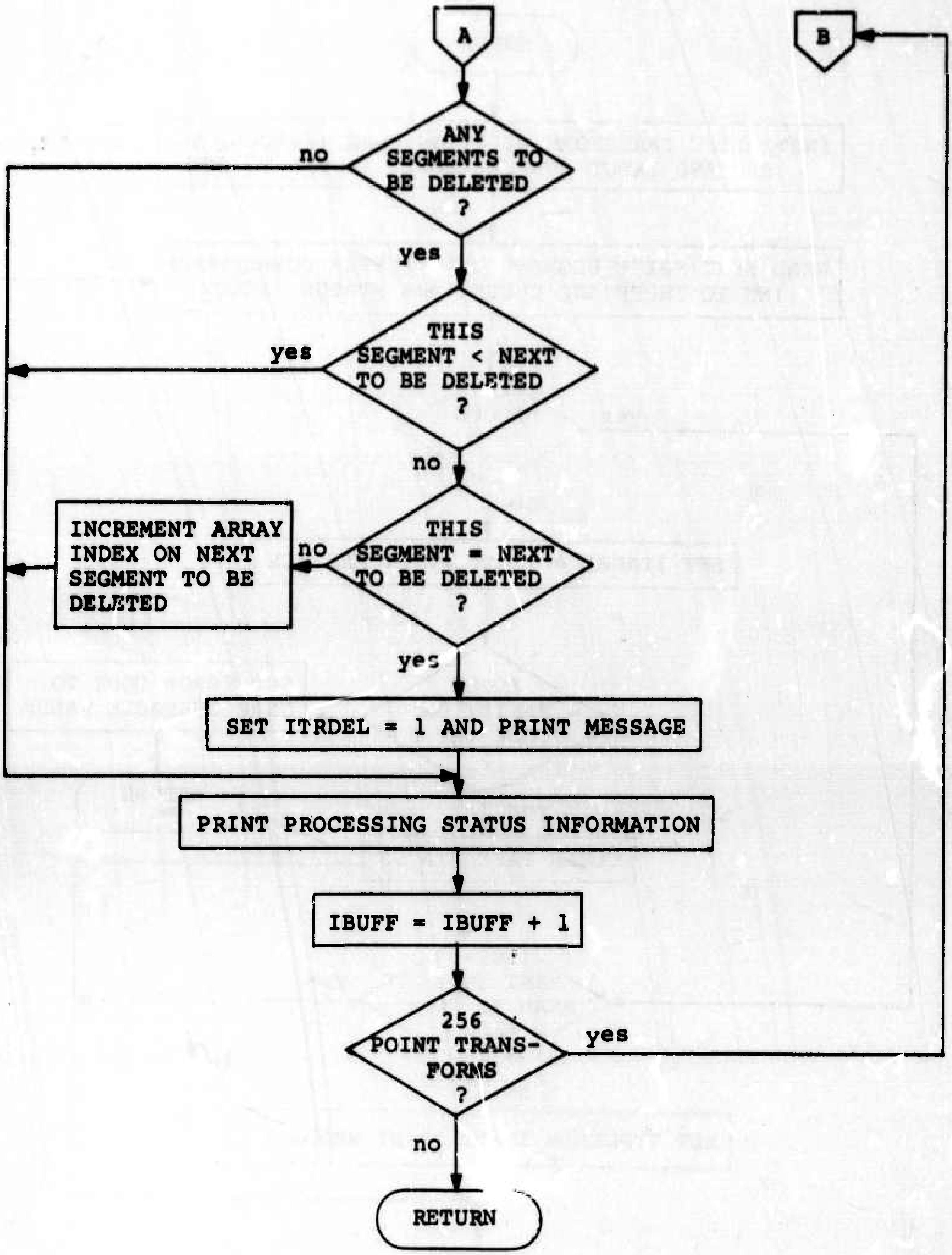


Figure V-21
SUBROUTINE INTIME
2 of 2 pages

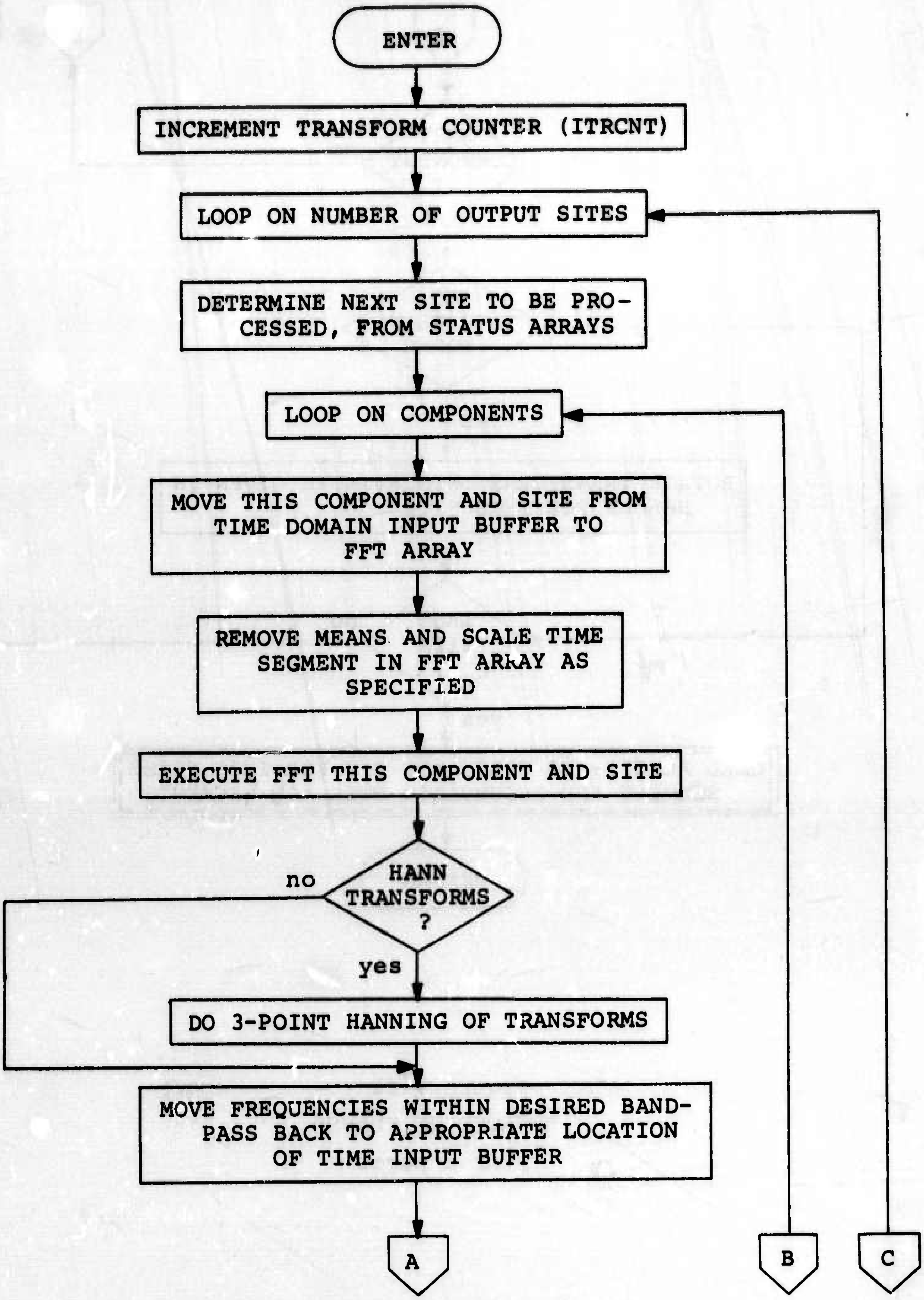


Figure V-22
SUBROUTINE TRANSF
1 of 2 pages

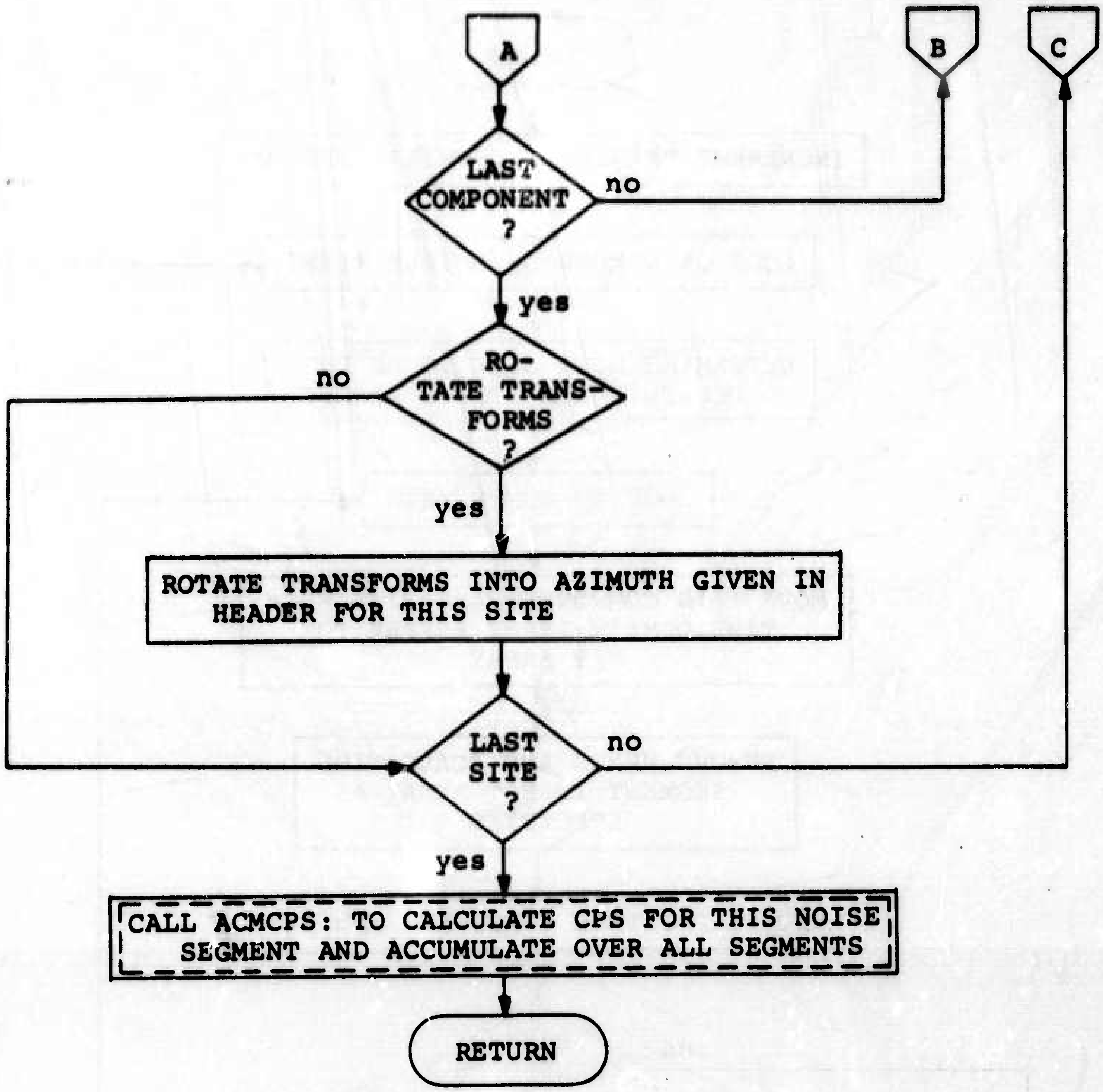


Figure V-22
SUBROUTINE TRANSF
2 of 2 pages

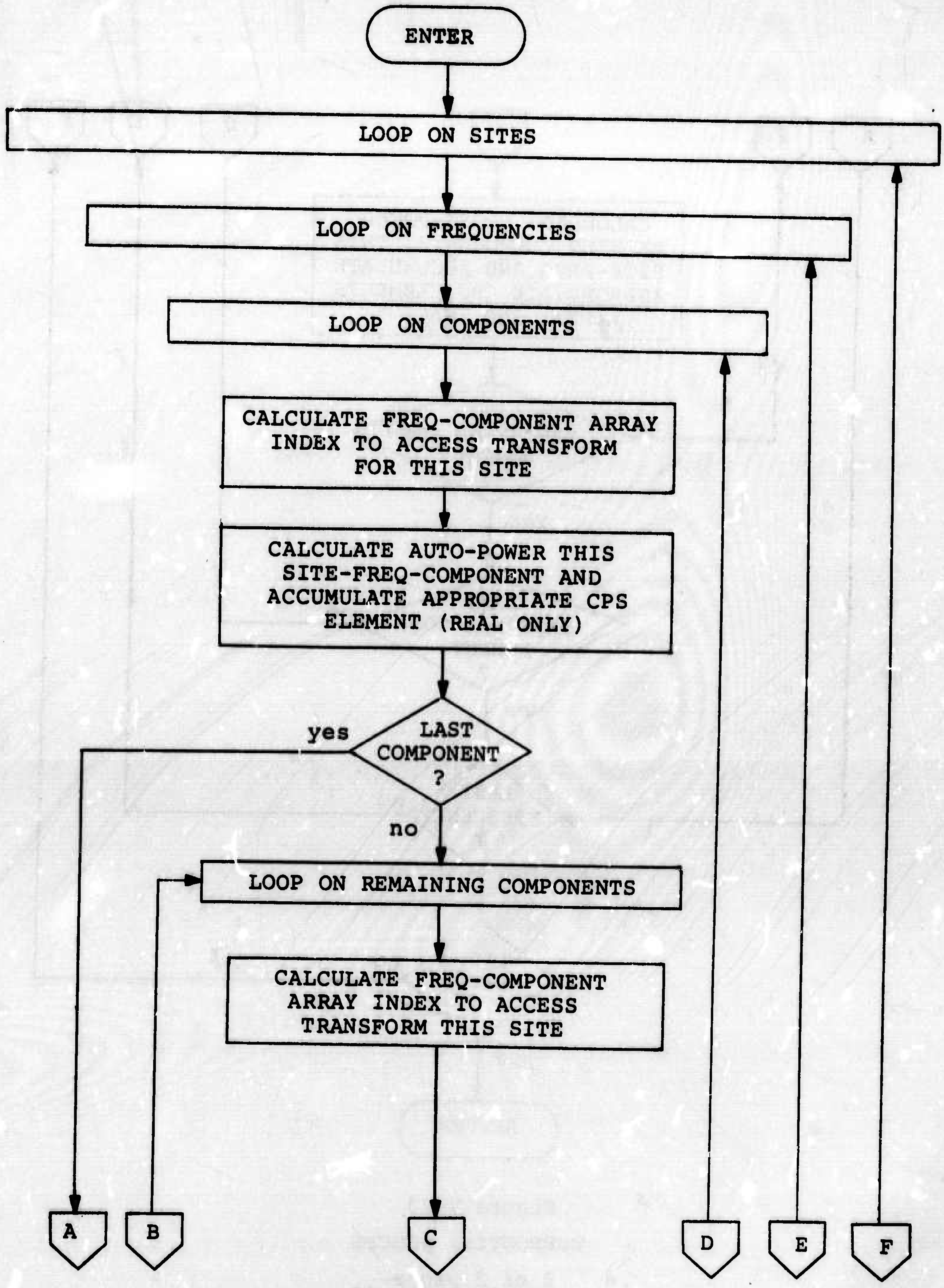


Figure V-23
SUBROUTINE ACMCPS
1 of 2 pages

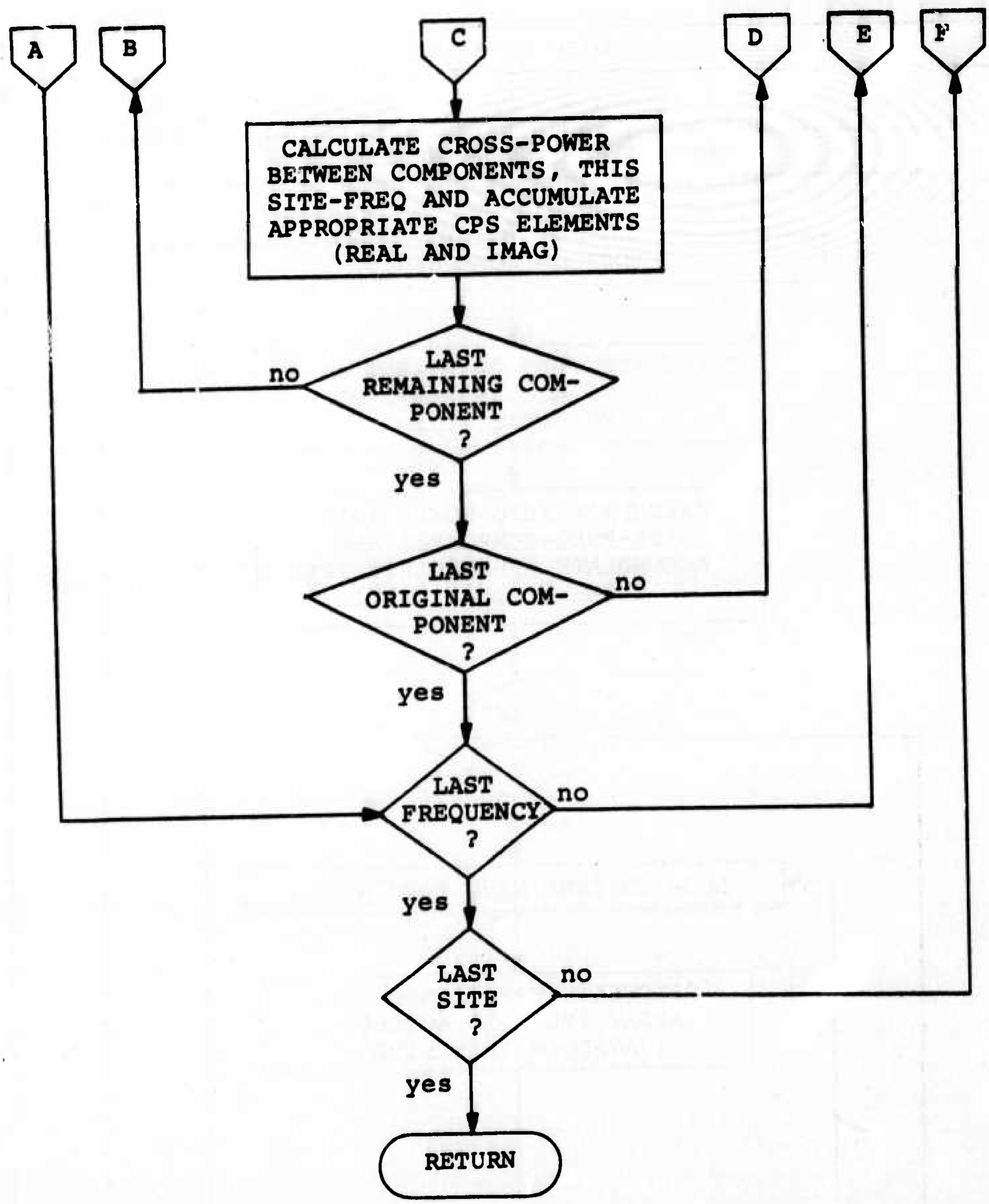


Figure V-23
SUBROUTINE ACMCPS
2 of 2 pages

power spectra of each component and site are provided. In addition, coherencies between all components at each site are calculated and plotted by subroutine COMCOH, Figure V-24.

Signal data for all segments to be processed are read from tape and the selected sites are output temporarily on disk by subroutine SGPREP (Figure V-25). Before storing the data on disk, trace scaling and mean removal is performed along with rotation to the primary beam direction if desired. A signal trace output tape can be generated for use by the trace analysis program LXTRAN. In addition to raw data traces of each component, there are two possible processed signal output traces at each site.

One type of signal processing which is performed by this package is the design and application of a two-channel MCF. The MCF is a Weiner filter designed from measured noise preceding the signal and a signal model corresponding to Rayleigh mode energy propagating on the vertical and radial components only. Signal on the radial component is assumed to precede that on the vertical by ninety degrees and have an amplitude difference which can be varied within the program. The MCF is applied to the expected Rayleigh portion of the signal traces only, with some overlap to account for discrepancies in arrival times.

A second type of signal processing is obtained by designing a ninety-degree phase shift operator. This operator is then applied to data on the radial component over the Rayleigh portion of signal and summed with the corresponding vertical component. The design of this operator is performed at event initialization time and is accomplished in the time domain. The operator is variable in length up to sixty-five time points.

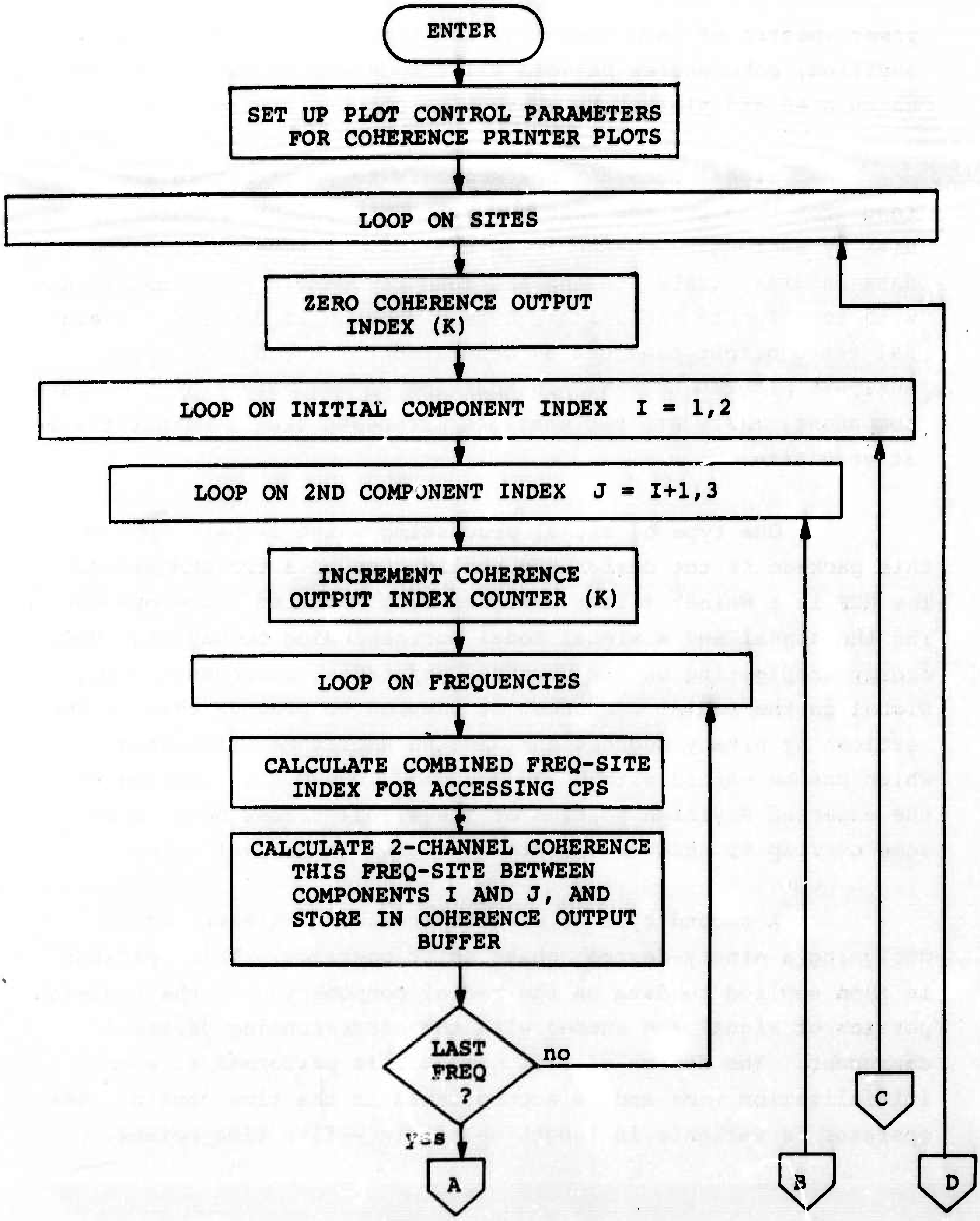


Figure V-24
SUBROUTINE COMCOH
1 of 2 pages

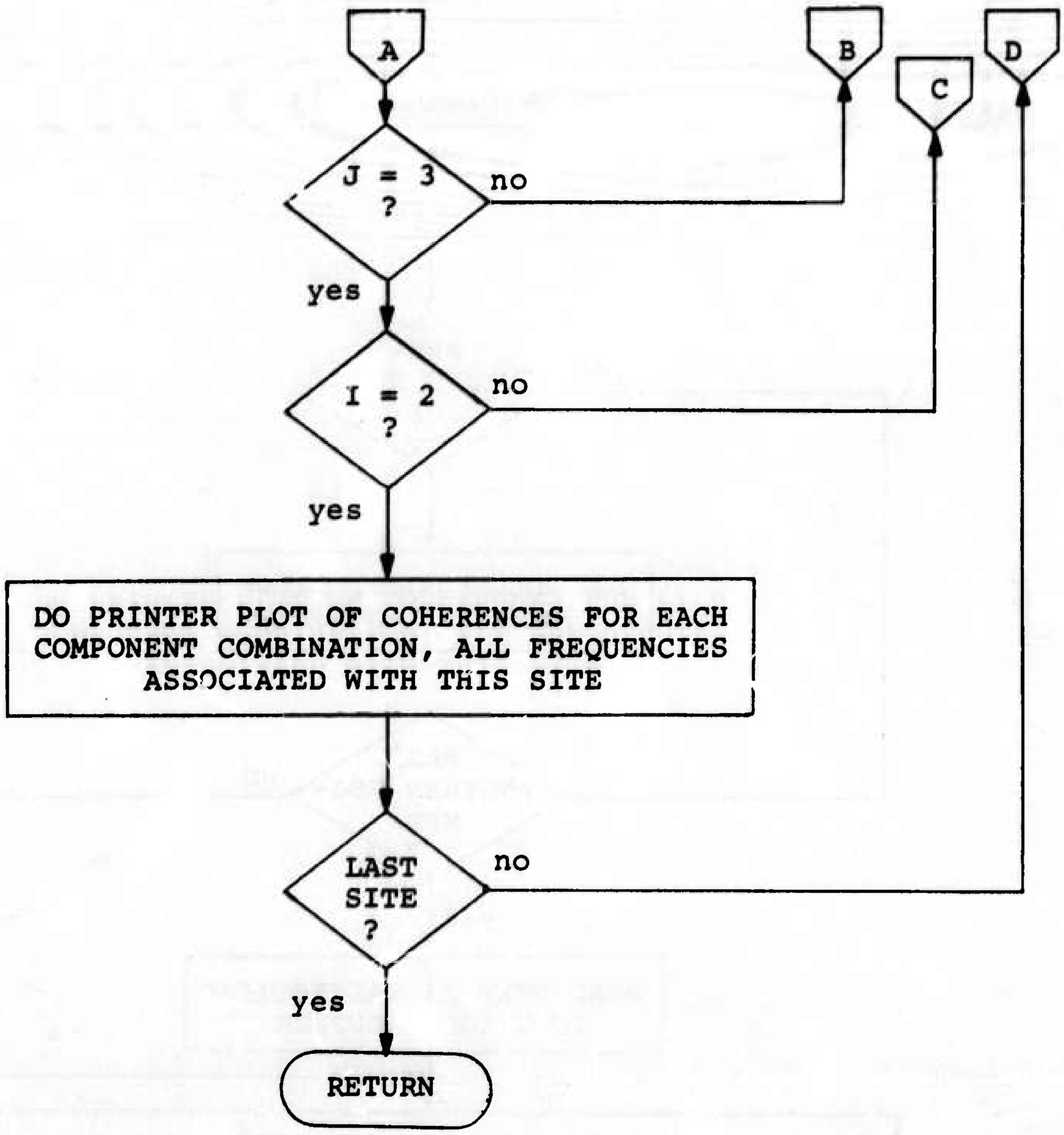


Figure V-65
SUBROUTINE COMCOH
2 of 2 pages

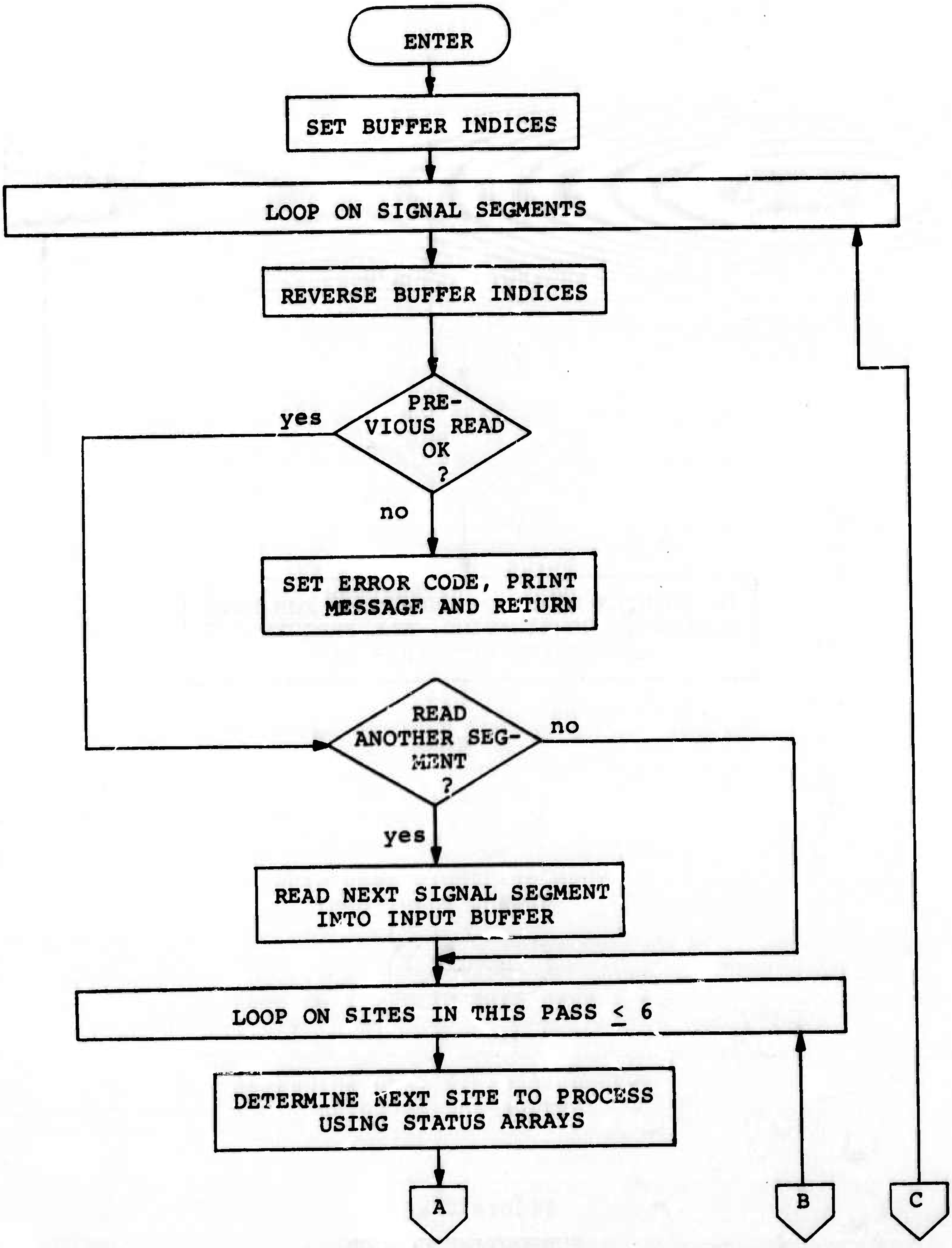


Figure V-25
SUBROUTINE SGPREP
1 of 2 pages

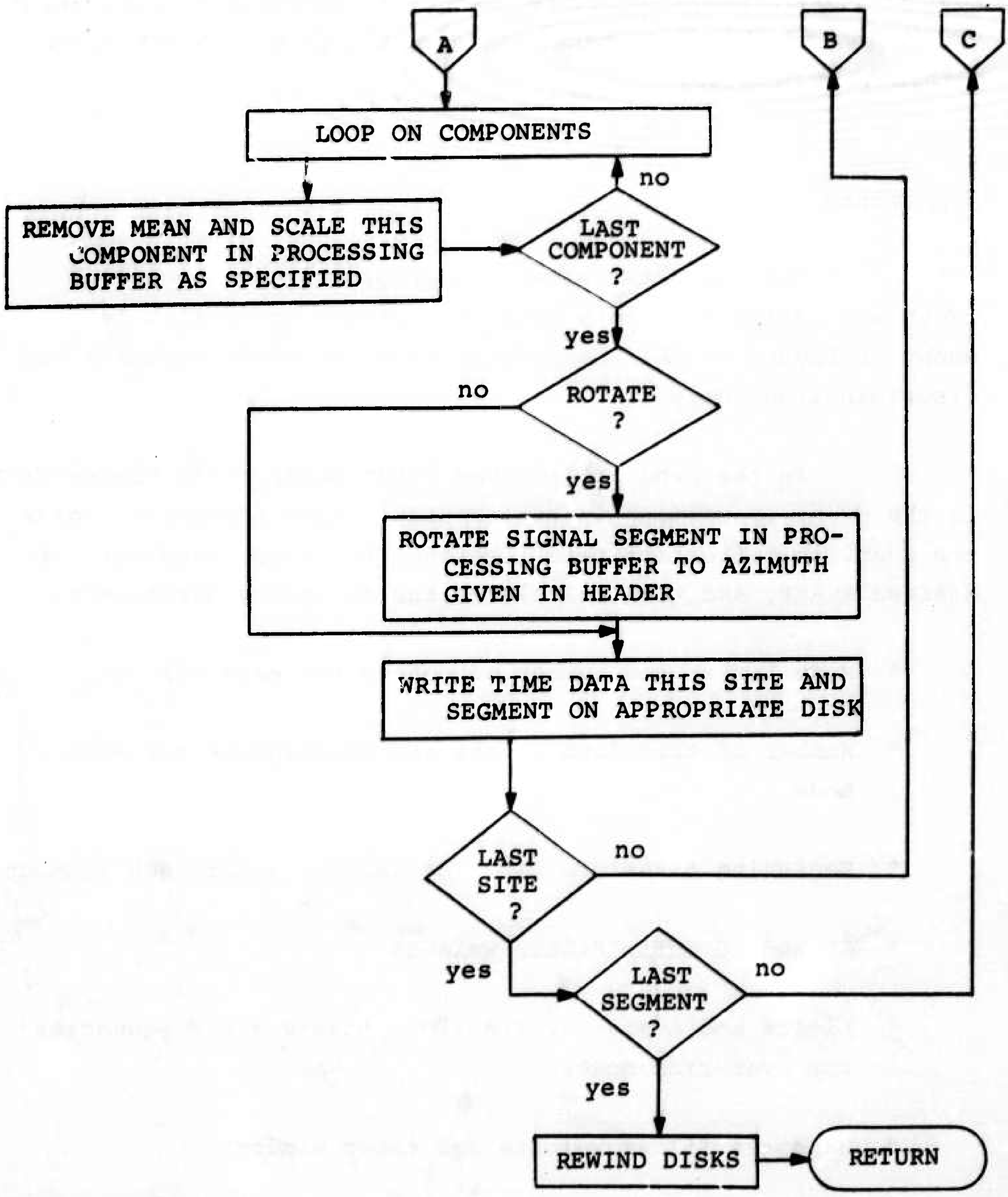


Figure V-25

SUBROUTINE SGPREP

2 of 2 pages

Signal processing and output is performed by subroutine SIGOUT shown in Figure V-26. In addition to tape input, any or all of the above mentioned traces may be CALCOMP plotted within this program.

7. LXTRAN

The raw data traces and/or processed traces from LXGEN are analyzed in this program. LXTRAN basic flow is shown in Figure V-27. The program performs event spectral and discrimination analysis.

In the program flow the first major task, Figure V-28 is the event processing initialization. This subroutine reads the event specification card, searches the input tape for the desired event, and then calculates the following parameters:

- Mode limits and number of points for each station
- Number of transform points and frequencies for each mode
- Beginning transform time for each mode for each station
- LR and LQ Chirp Filter weights
- Limits and number of transform points and frequencies for over-ride modes
- Bandpass filter weights and taper windows
- Fortran index of first data point for each mode

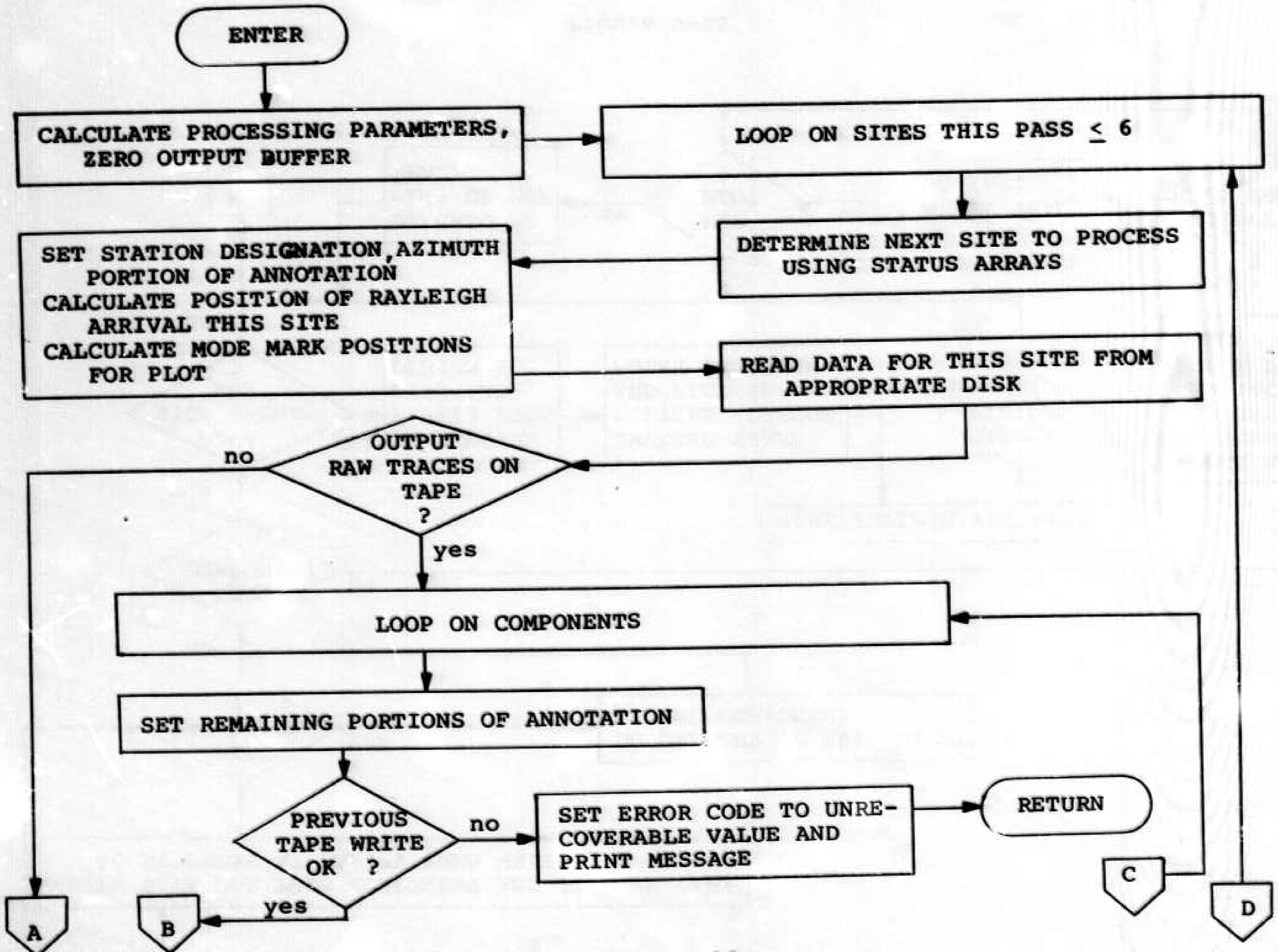


Figure V-26

SUBROUTINE SIGOUT

1 of 3 pages

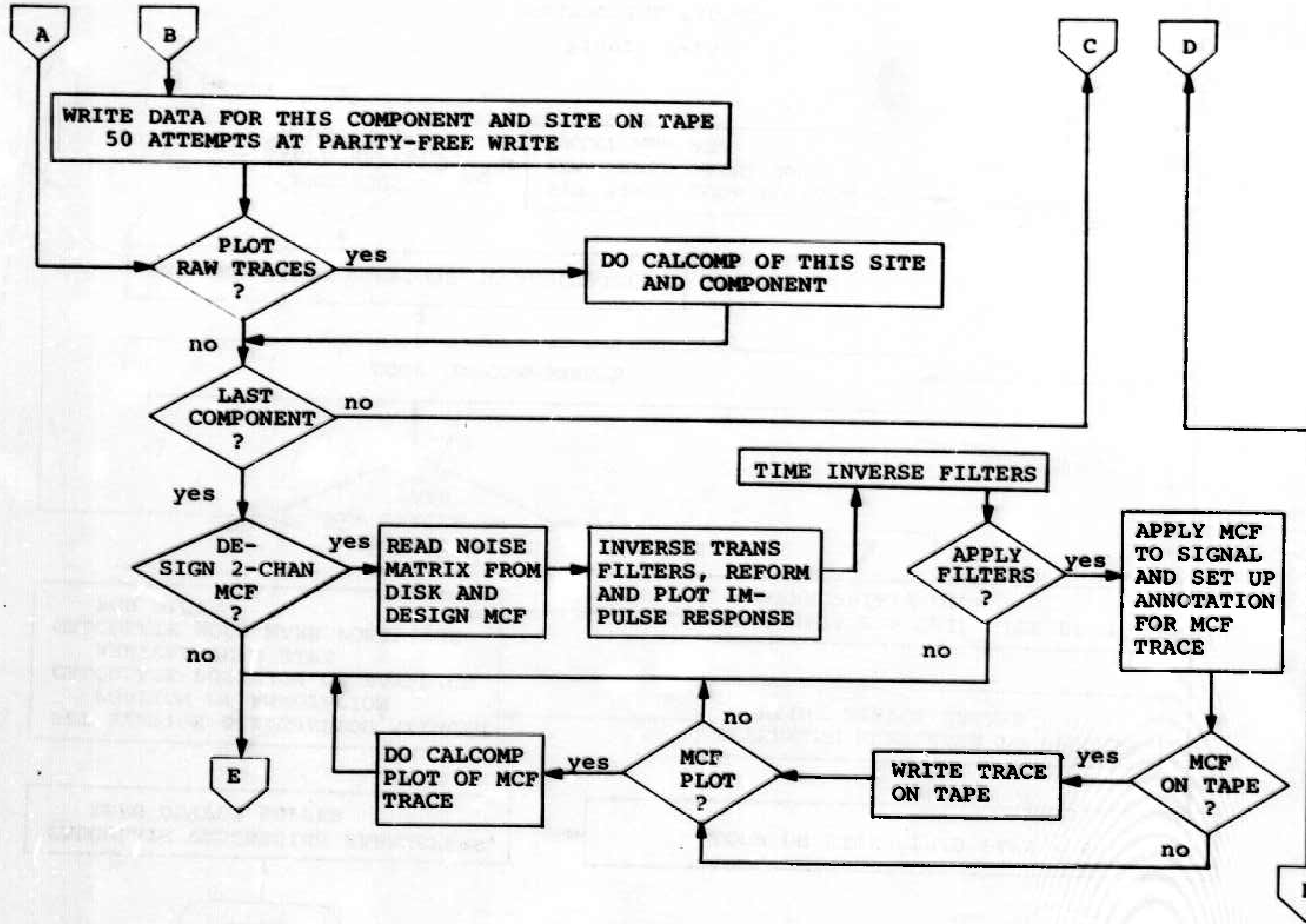


Figure V-26

SUBROUTINE SIGOUT
2 of 3 pages

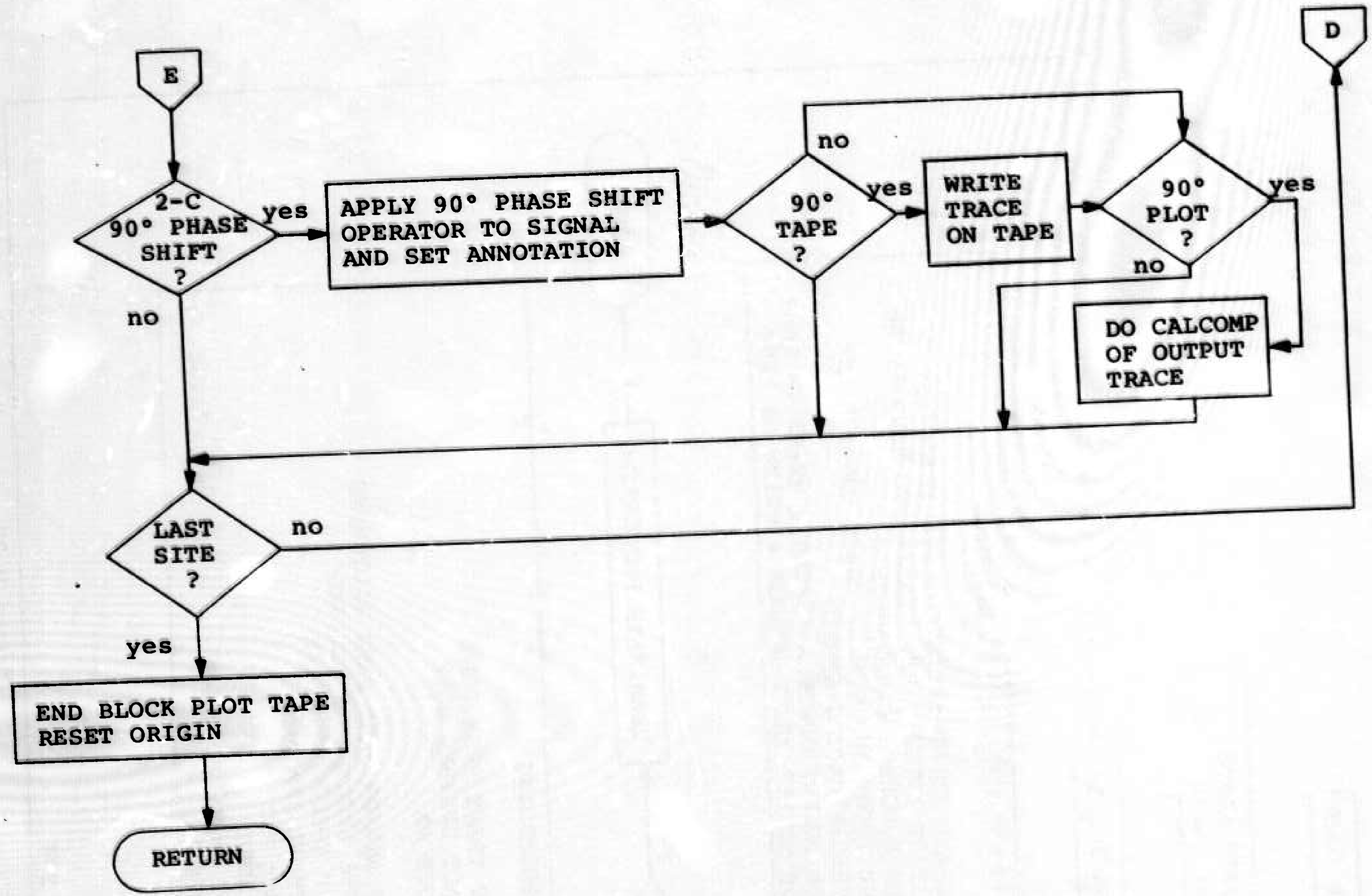


Figure V-26
SUBROUTINE SIGOUT
3 of 3 pages

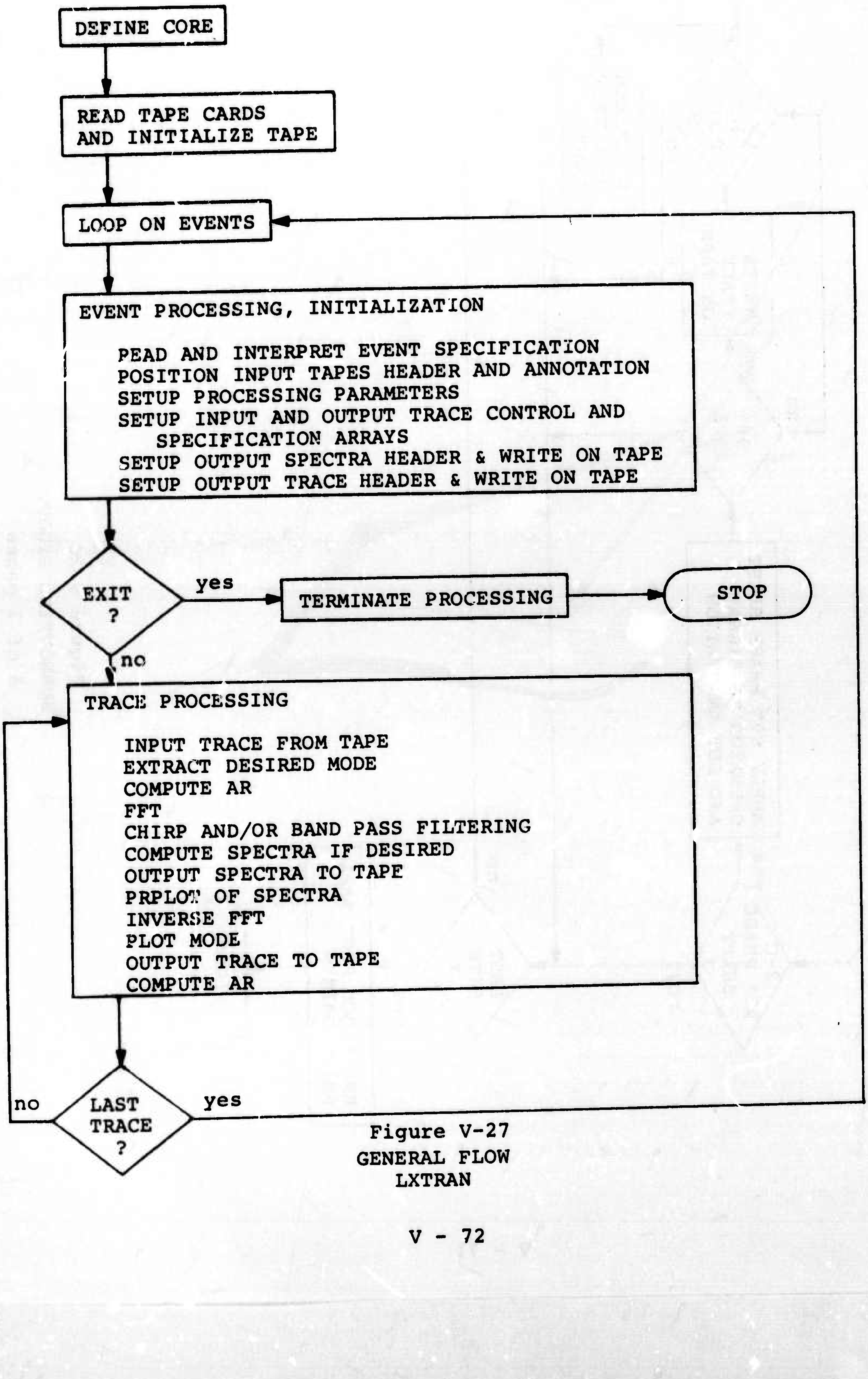


Figure V-27
GENERAL FLOW
LXTRAN

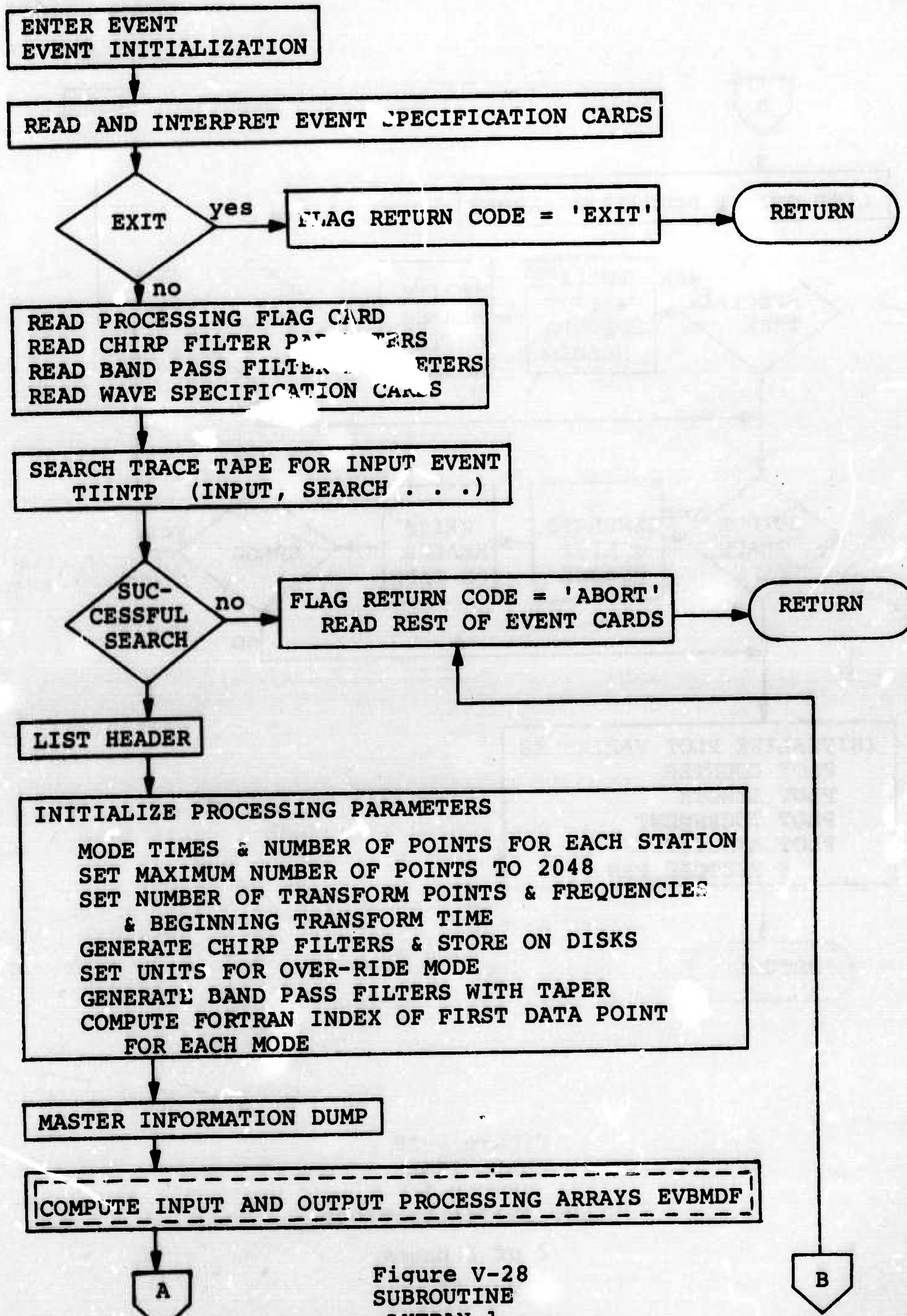


Figure V-28
SUBROUTINE
LXTRAN 1
(EVENT INITIALIZATION)
1 of 2 pages

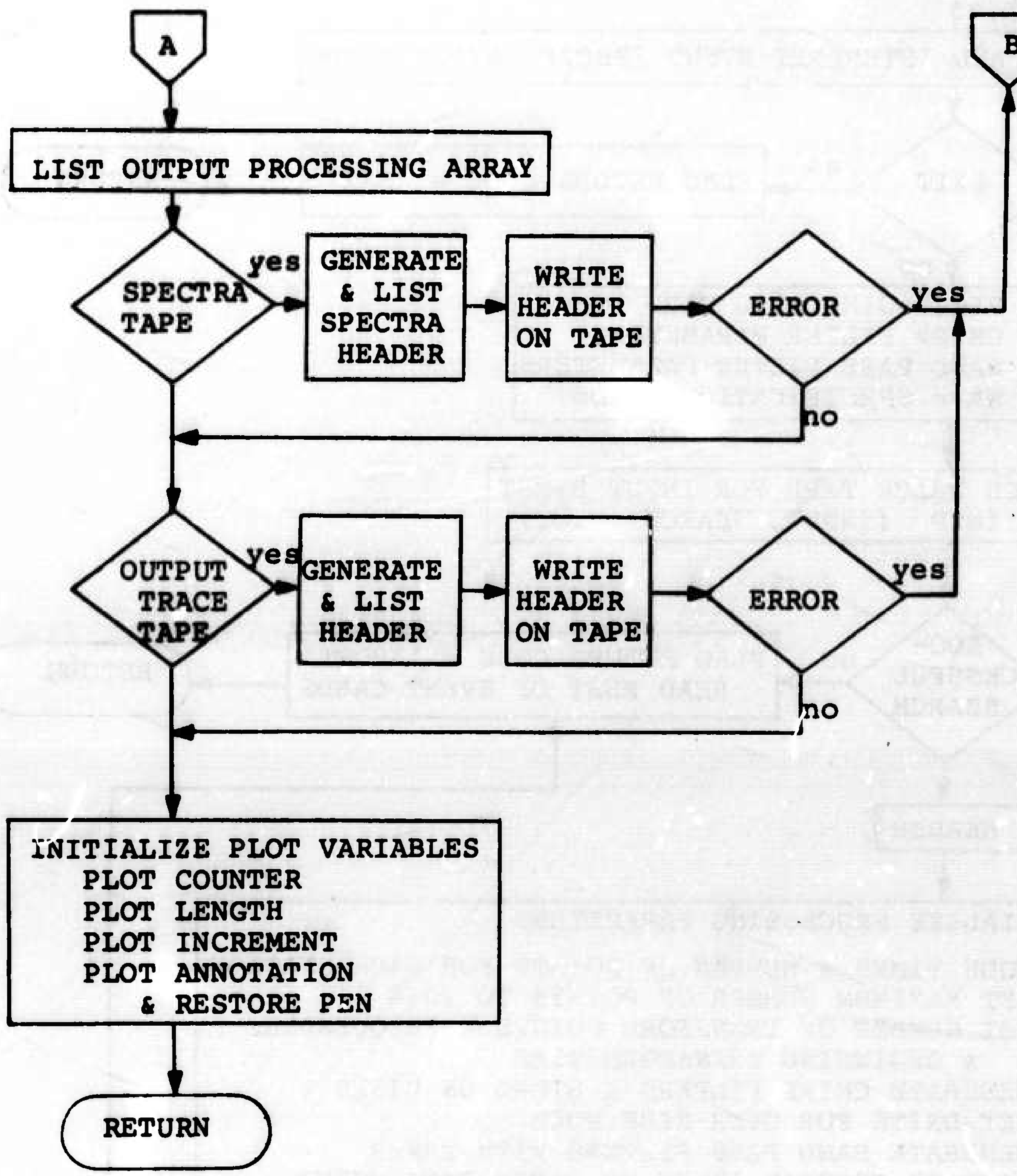


Figure V-28
SUBROUTINE
LXTRAN 1
(EVENT INITIALIZATION)

2 of 2 pages

After setting up all parameters, a master information summary is printed to aid the analyst in later data studies. Then the subroutine EVBMDF, Figure V-29, is called to initialize the trace counter parameters, to read the trace processing cards, and to generate the input and output trace processing arrays. After return from EVBMDF, the event initialization subroutine summarizes the output processing array, initializes the input spectra and time domain data tapes, and generates the Calcomp plot variables if they are needed.

The trace processing subroutine is then called, Figure V-30. This subroutine reads the input trace from tape and partitions it into the desired mode, calculates the sum of the absolute values of the data points, and Fourier transforms the mode of interest. Then any set of the following options is performed:

- Punch transform for later use as a master waveform
- Apply chirp or master waveform filter
- Apply bandpass filter
- Calculate power spectra
- Plot power spectra on printer
- Output power spectra to tape
- Inverse Fourier transform to time domain
- Calculate the sum of the absolute values of the output data points

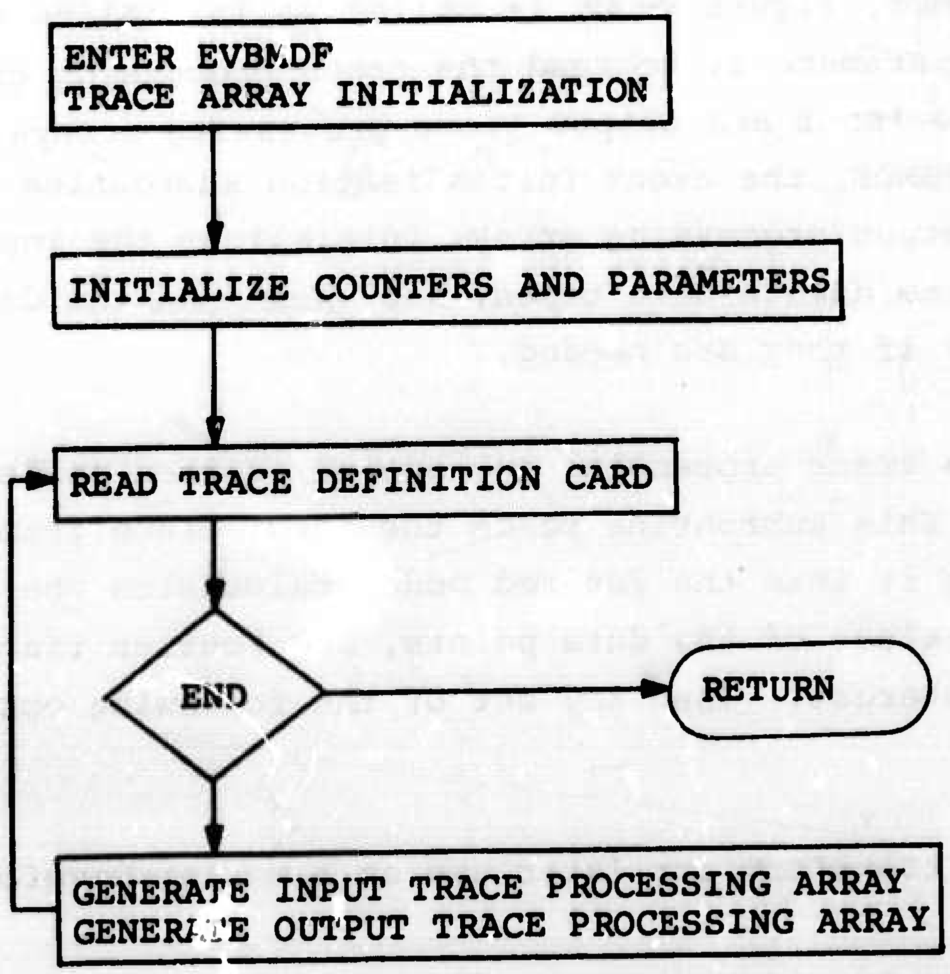


Figure V-29

SUBROUTINE EVBMDF

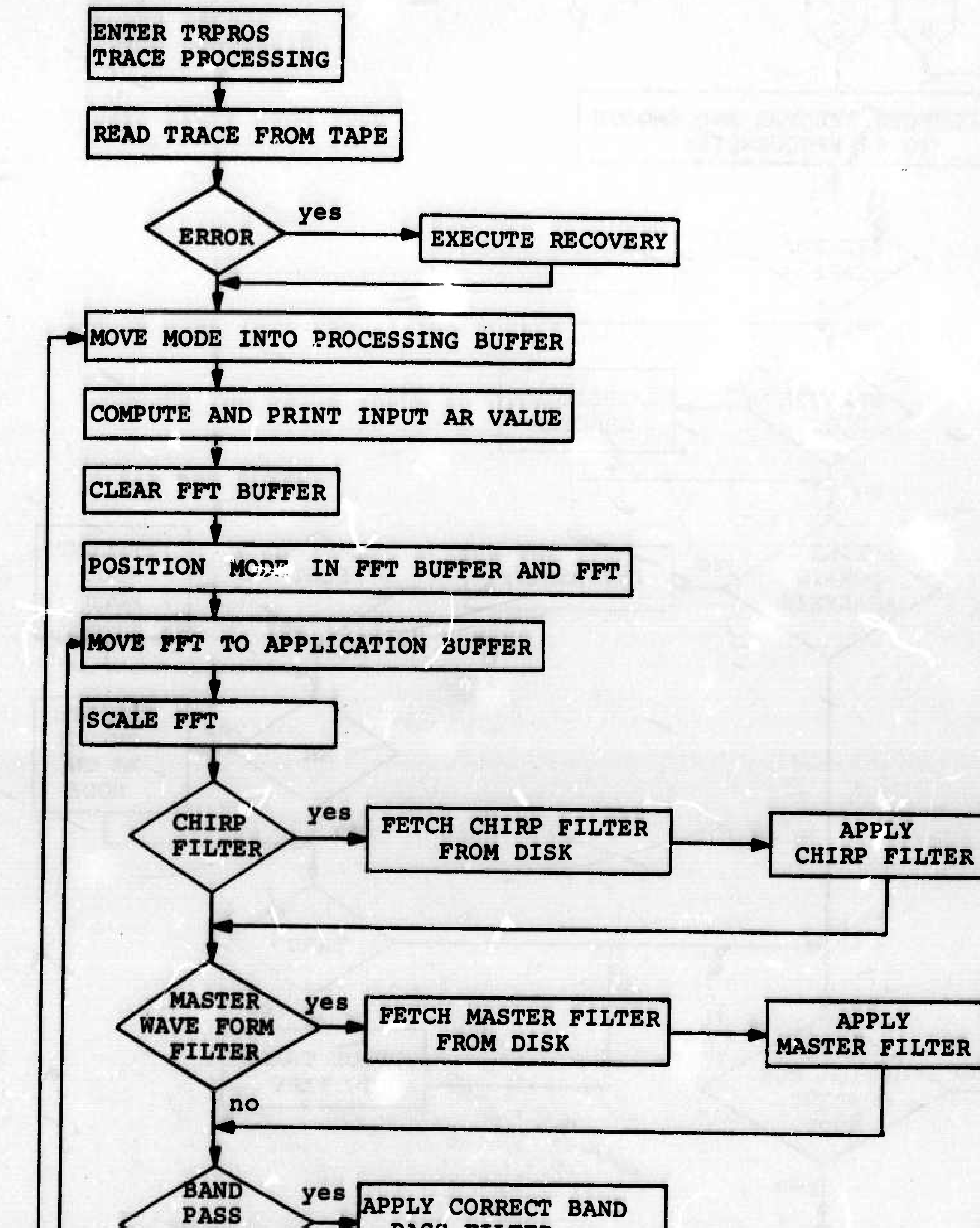


Figure V-30
SUBROUTINE LXTRAN 2
(TRACE PROCESSING)
1 of 2 pages

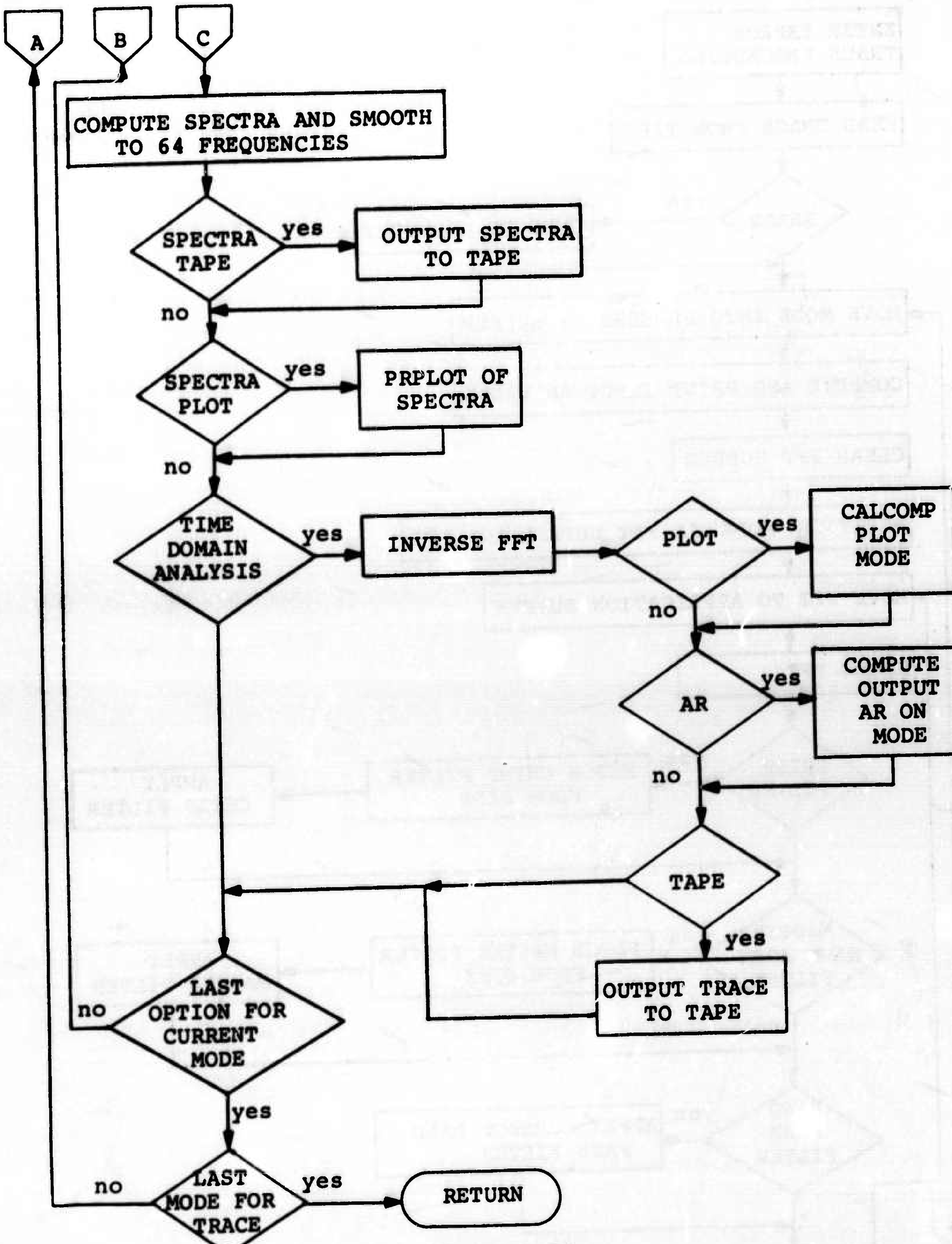


Figure V-30
SUBROUTINE LXTRAN 2
(TRACE PROCESSING)
2 of 2 pages

- Calcomp plot time trace

- Output time trace to tape

The subroutine is then repeated for the next set of options for the mode. After all options for each mode and all modes are processed, program control is returned to the main program, which checks to see if all input traces have been processed. If not, the trace process subroutine is repeated until all traces have been processed; if so, a new event or 'exit' card is read.

8. LXGRP

LXGRP determines empirical group velocity curves from recorded surface waves. Power density spectra are computed from each of a sequence of short gates covering the time period of the surface wave. The location of the peaks in frequency for each gate are associated with the center time of the gate. The program outputs a printer plot showing the location of these peaks as a function of their travel time. This display will in general consist of several continuous curves. These are interpreted as the group velocity curves for the various modes in the wave.

One difficulty associated with this technique is the necessity to compute power density spectra from very short time gates. Conventional techniques for spectral estimation in this case have unacceptable spectral windows. To overcome this a spectral estimation procedure by John Burg is used.[6]

The input to the program is time-domain data from LXTRAC. The user will specify by a card input the following parameters:

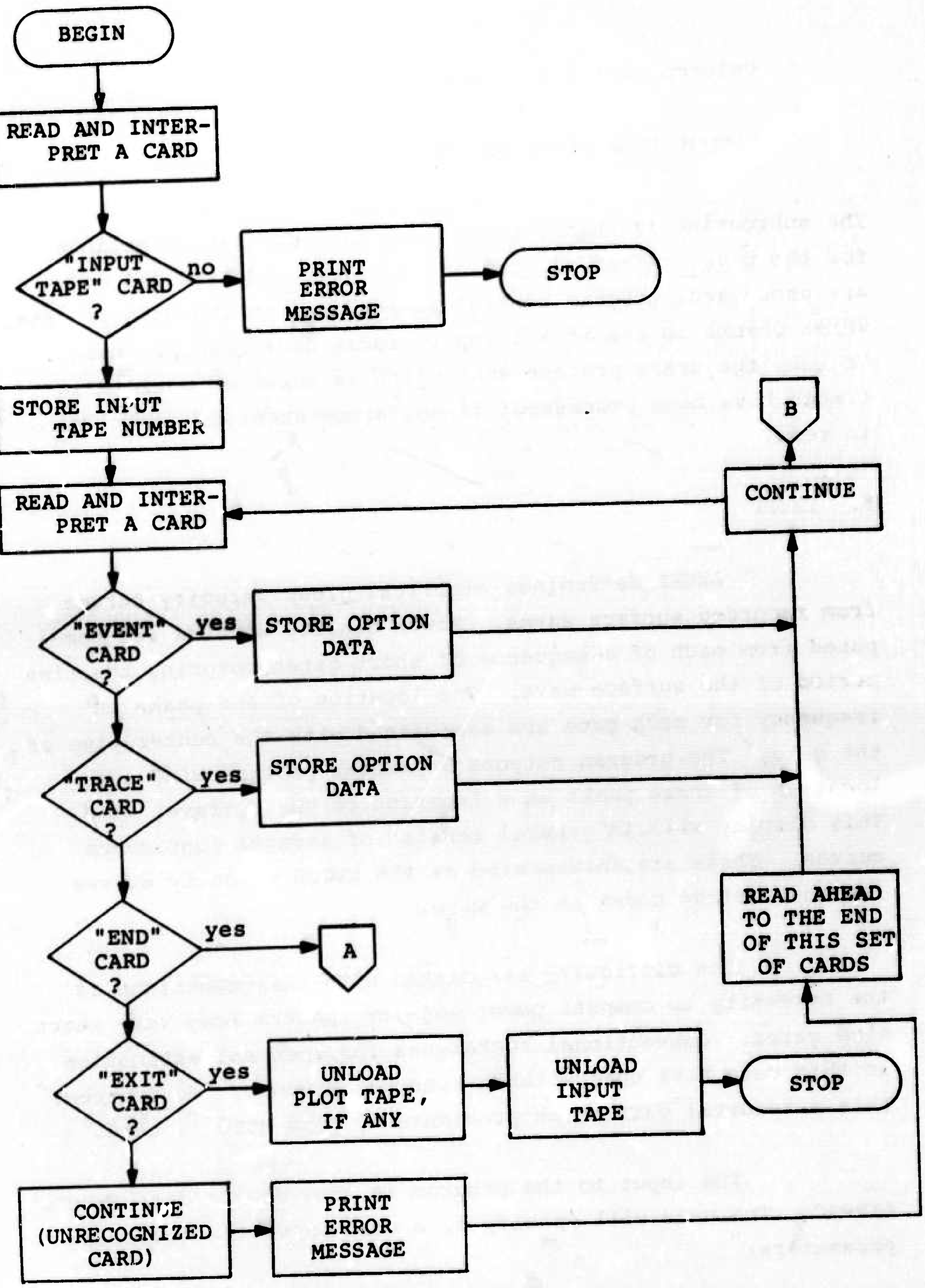


FIGURE V-31
GENERAL FLOW
LXGRP
1 of 2 pages

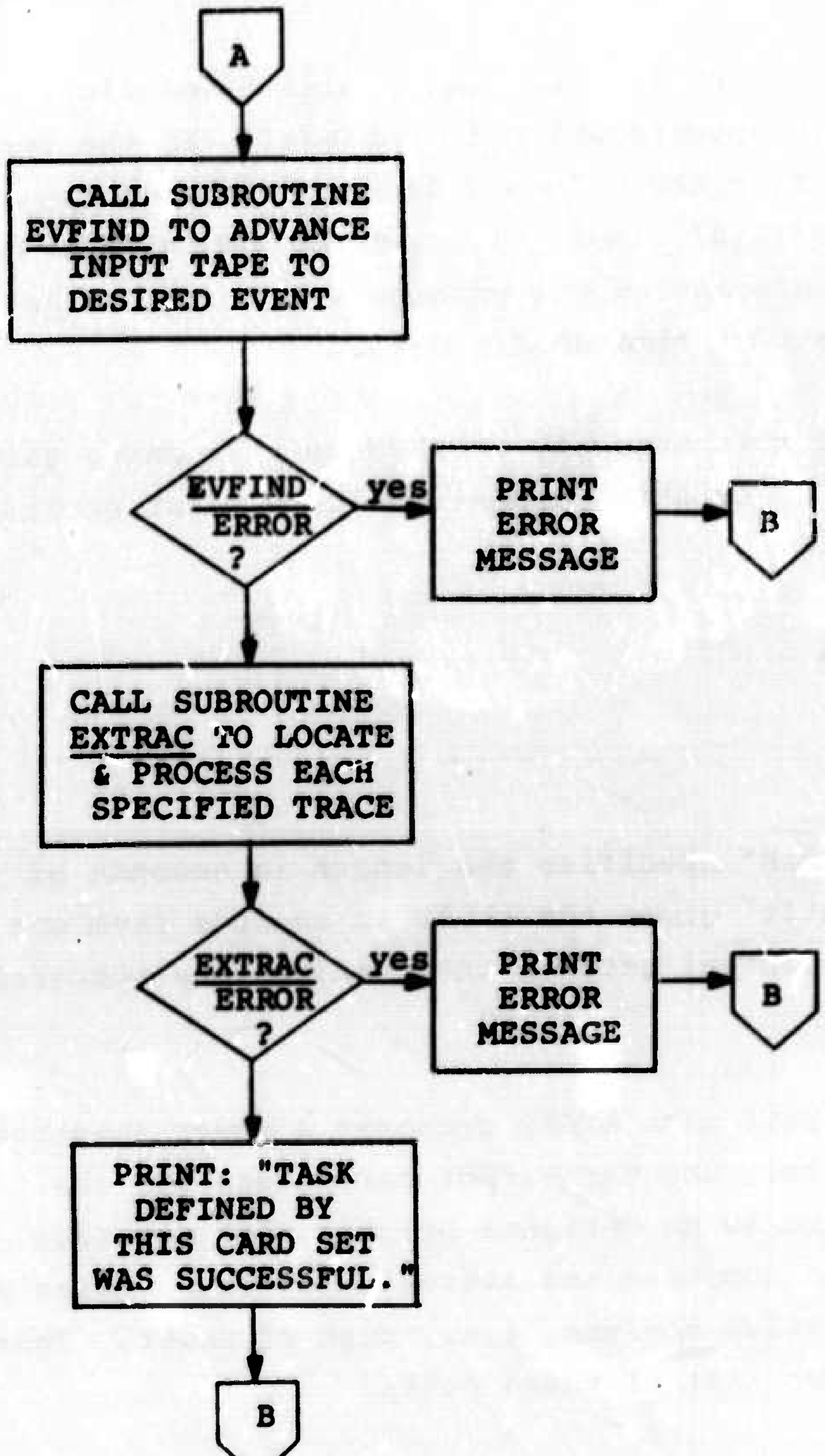


FIGURE V-31
GENERAL FLOW
LXGRP
2 of 2 pages

1. The event name

2. The trace number (this gives the site and component)

3. The trace-segment limits, i.e., initial and final times. This specification is optional. In the default situation the values will be calculated internally from arrival times, given in the LXTRAC data headers. With this information the program will isolate the given segment of time domain data.

Then, for this segment, LXGRP does a "running gate spectral analysis." For this purpose the card input provides two more parameters:

1. Gate length

2. Gate shift

"Gate length" specifies the length in seconds of each gate. "Gate shift" gives the shift in seconds from one gate to the next sequential gate in the running gate spectral analysis.

For the first gate LXGRP computes a power spectrum (frequency limits, etc., are card-input parameters for the given trace) and there is an optional printer plot for this spectrum. LXGRP then computes and stores those frequencies at which there is a relative maximum, i.e., peak of power. There is an optional printer list of these peaks.

Now LXGRP iterates this process, shifting the gate each time by the time "gate shift," until some gate extends beyond the final time for the trace-segment. Thus the number of gates is defined implicity by the other parameters.

For each gate there is thus defined a set of "peaks" (there will always be at least one) and among these peaks there is some "greatest," i.e., some frequency at which the power is greater than or equal to those powers at other "peak frequencies." This is called the "maximum-peak frequency" for this gate. Thus, for each gate, there is defined a corresponding frequency. This is associated with the midpoint time of the gate. There results a function with independent variable = time, dependent variable = frequency.

Similarly, one defines another function, "frequency of the second-greatest peak" (with a default value of 0.0 for cases where there is no "second peak"), and "third-greatest," etc.

The graphs of these functions are printed out by a call to "PRPLOT." Usually there will be just two functions, "greatest-peak-frequency" and "second-greatest-peak-frequency" printed out; however, there is an option for up to ten of these.

The call to PRPLOT" concludes the "running gate spectral analysis" for this trace segment and LXGRP goes on to pick up another trace-segment and continue to process, if more traces are specified. Any number of traces may be specified. LXGRP General Flow is shown in Figure V-31.

9. LXDISP

This program computes theoretical normal mode dispersion curves and approximate theoretical leaky mode dispersion curves, using Haskell's method.[6] The dispersion curves, plots of c (phase velocity) vs f (frequency), may be scanned with either f or c as the independent variable, i.e., we may either compute $f = f(c)$, or $c = c(f)$. There is also the option of:

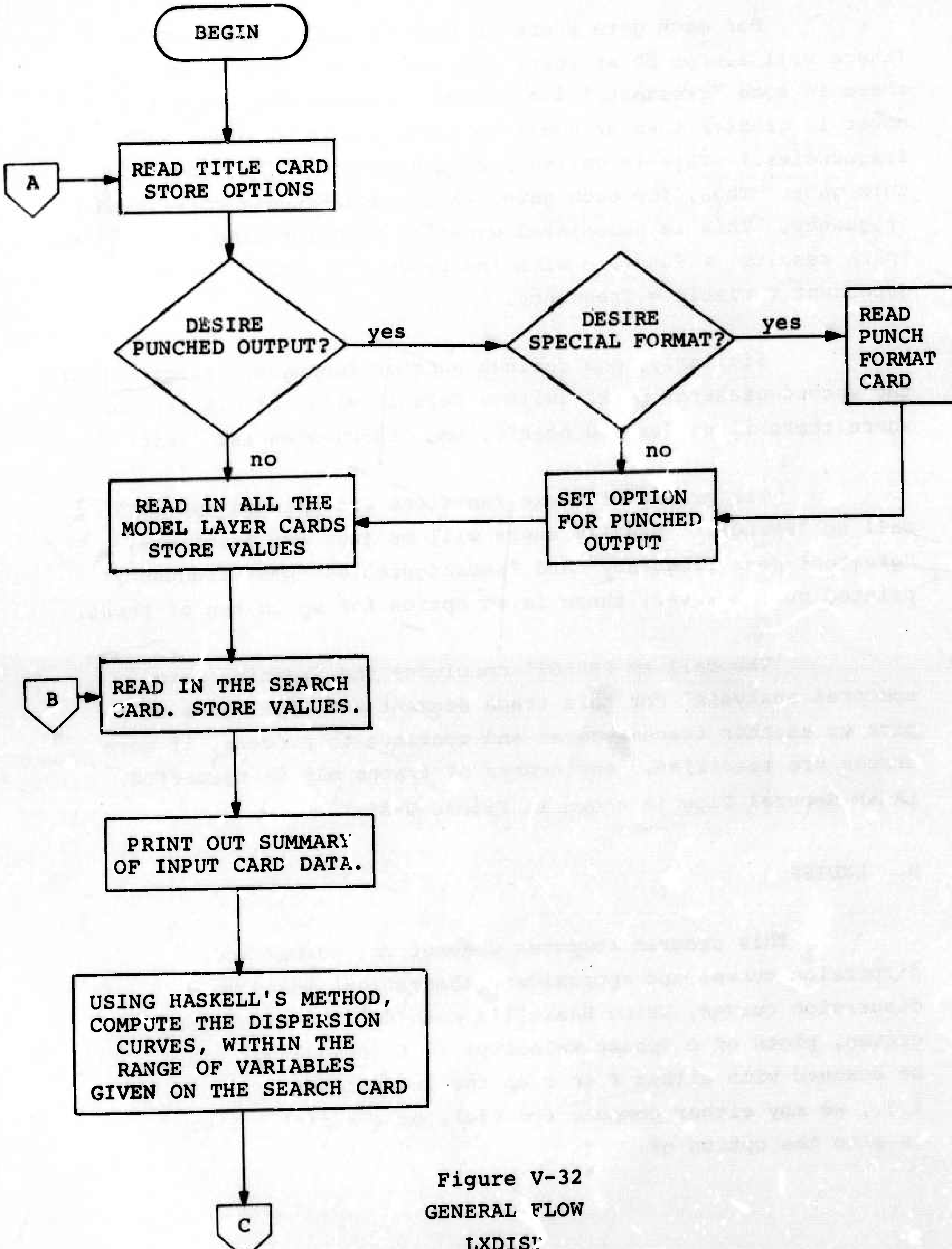


Figure V-32
GENERAL FLOW
LXDIST
1 of 2 pages

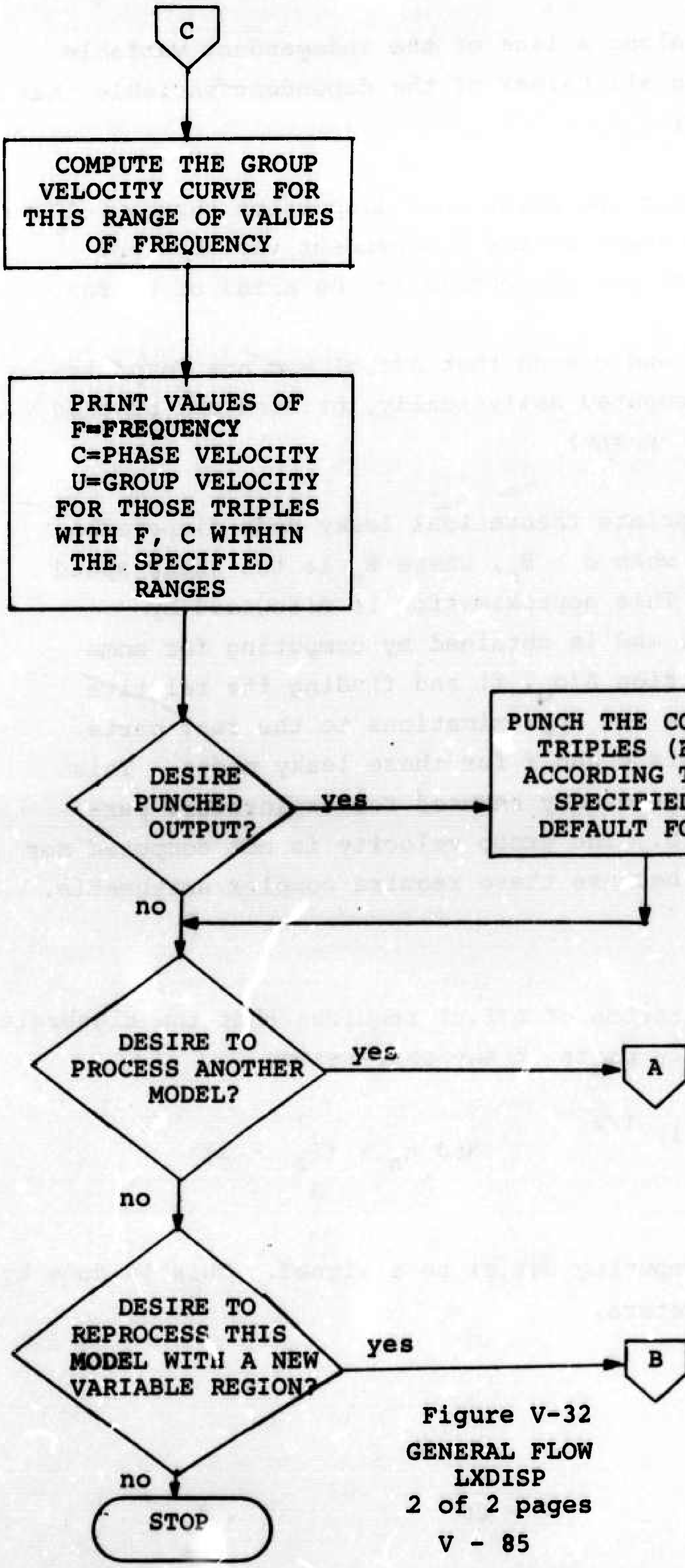


Figure V-32
GENERAL FLOW
LXDISP
2 of 2 pages

1. Searching along a line of the independent variable constant and finding all values of the dependent variable that makes $\Delta(f,c) = 0$ or;

2. After finding one point on a dispersion curve, follow that curve in equal steps of the independent variable and then do the same with all the curves in the areas of search.

Once the value of f and c such that $\Delta(f,c) = 0$ are found the group velocity is computed analytically, printed and punched (if punch option is chosen).

The appropriate theoretical leaky mode dispersion curves are computed when $c > B_n$, where B_n is the shear speed in the half-space. This approximation is discussed by Gilbert and Laster[8], and is obtained by computing for some $c = c_o > B_n$ the function $\Delta(c_o, f)$ and finding its relative minima. These points are approximations to the real parts of the complex numbers c and f for these leaky modes. This mode of operation should only be used for exploratory purposes and when IC = 0. The group velocity is not computed nor is the attenuation, because these require complex arithmetic.

The computation of $\Delta(f,c)$ requires that the algebraic sign of the imaginary parts of the expressions

$$\eta_p \iota = \left(\frac{c^2}{\alpha^2} - 1\right)^{1/2} \quad \text{and} \quad \eta_s = \left(\frac{c^2}{B^2} - 1\right)^{1/2}$$

that are used in computing $\Delta(f,c)$ be assigned. This is done by setting input parameters.

Any consistent set of units may be used, e.g., if time is in microseconds and distance is in millimeters, then speed should be given in cycles per microseconds. Only the density in any layer may be normalized to one and the other density changed by the same ratio.

Up to a 30 layered model may be used, but the calculation time increases with the number of layers in the model.

The input data cards specify the model by giving the number of layers and for each layer (including the half-space) the P-wave speed, S-wave speed, density and thickness.

Then for each area to be searched the above mentioned options are specified, together with limits and increments of c and f.

The output list contains the program number and the title plus a listing of all the input parameters, and for each point on a dispersion curve the values of F, K, C, and U (for normal modes), where F is frequency, K = 2ΠF/C, C is phase velocity, and U is the group velocity.

The punched output consists of one card for each triple of values (frequency, phase velocity, group velocity). These cards are formatted for input to the program LXVCTT. LXDISP General Flow is shown in Figure V-32.

10. LXVCTT

This program has as its sole input the punched deck output of LXDISP (q.v.). From this input LXVCTT produces two Calcomp plots:

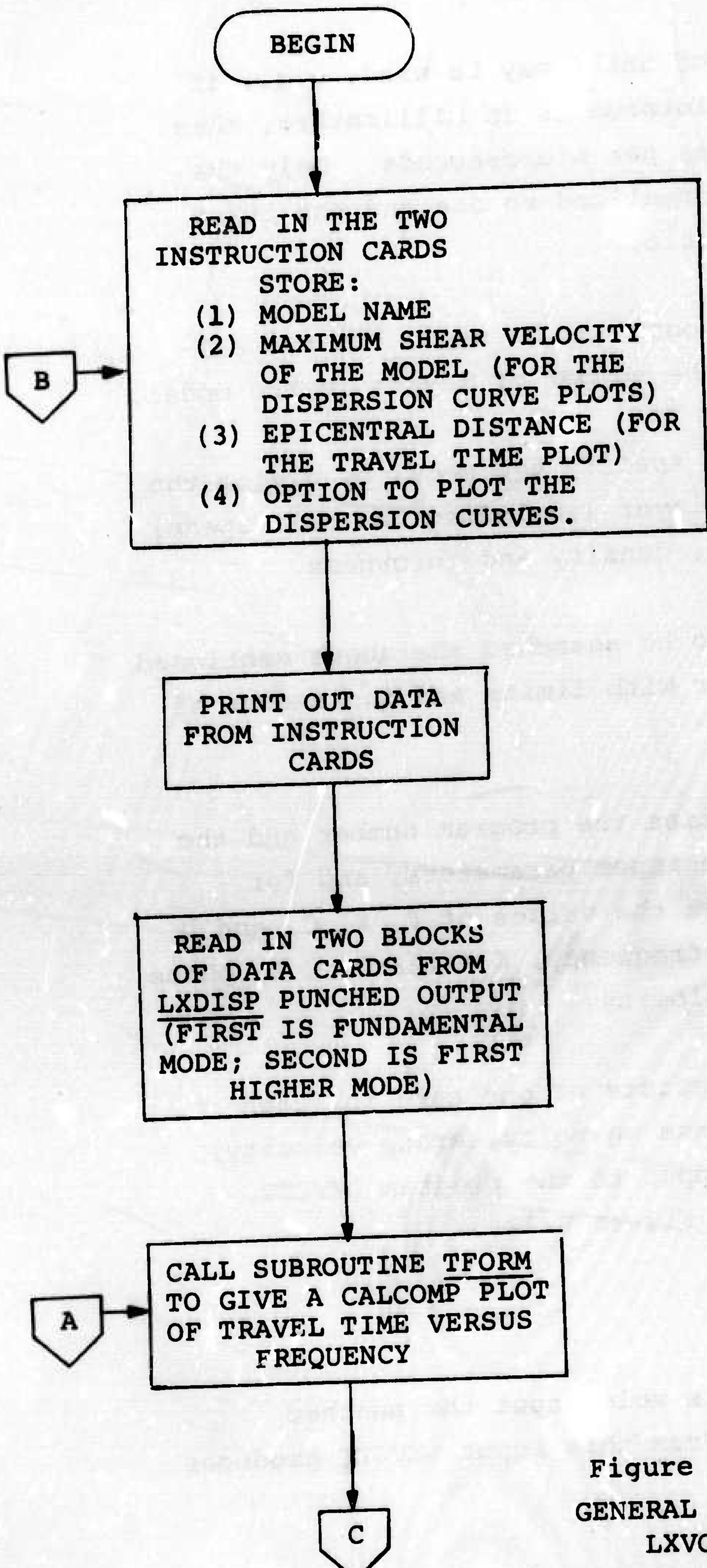


Figure V-33
GENERAL FLOW
LXVCTT
1 of 2 pages

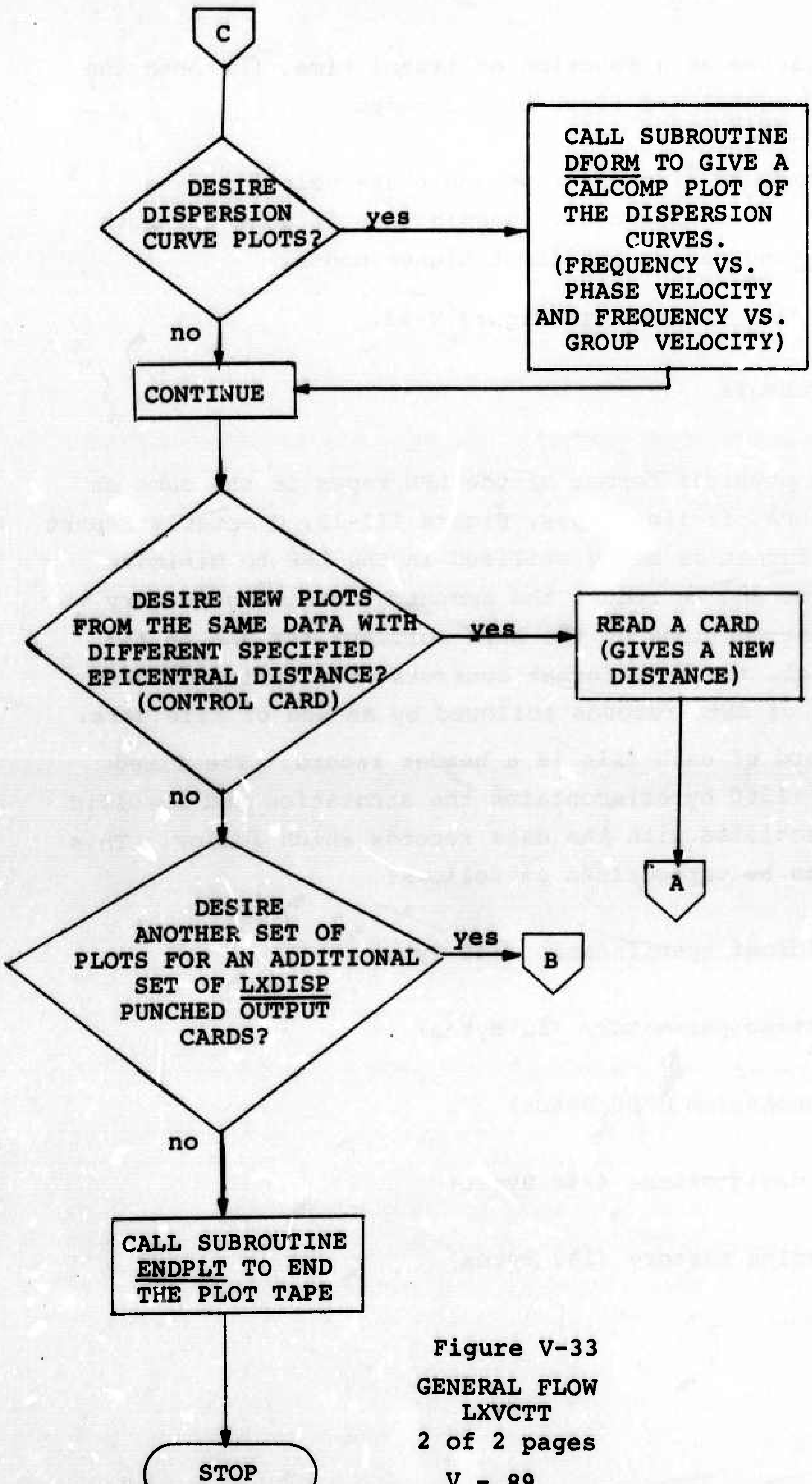


Figure V-33
GENERAL FLOW
LXVCTT
2 of 2 pages

1. Frequency as a function of travel time, for both the fundamental and first higher modes.

2. A compound plot of group and phase velocity as a function of frequency. Again this is done for both the fundamental and first higher modes.

LXVCTT General Flow is shown in Figure V-33.

C. LPE TAPE FORMATS

The physical format of the LPE tapes is the same as that for the ALPA off-line tapes, Figure III-12, Quarterly Report No. 3.[3] This format is being utilized in the LPE to minimize tape search time and to reduce the amount of coding necessary to modify pertinent sections of the ALPA software for use in the LPE. In general, the tape format consists of a series of data files, a group of data records followed by an end of file mark. The first record of each file is a header record. The fixed length header (1360 bytes) contains the annotation and specific parameters associated with the data records which follow. This information can be categorized as follows:

- Data format specification (40 Bytes)
- Processing parameters (60 Bytes)
- PDE annotation (120 Bytes)
- Array designations (960 Bytes)
- Processing history (180 Bytes)

Following the header record in each file is a sequence of data records. All of the data records in a particular file are of a specific format depending on the contents of the data stored. The basic data formats are:

- LXTDAT - time domain multi-station traces (3 components for each station)
- LXTRAC - time domain multi-station traces (3 components with/without 2 component MCF or Beam Steered traces for each station)
- LXFDPS - frequency domain single channel power spectra

These categories cover the primary needs for large volume data processing.

One other tape format is utilized. This is the format of the library tapes generated by the LXMERG program. The format for the library tape was chosen to make it compatible with the QCEDIT program, i.e., the format is similar to the ALPA library tape format since LXEDIT tape input is a modified section of the ALPA software QCEDIT. The complete LPE library tape format is shown in Appendix A.

D. Future Plans

During the next quarter, definition will be completed for the LXMULT program and coding will be completed and/or debugged on the programs LXMERG, LXGRP, and LXMULT. It should be pointed out that final program check out will not be completed until field tapes are received from the LPE stations. The use of field tapes to debug the LXMERG program is of major importance since current test tape can not cover all of the possible conditions which may be encountered in merging the field tapes. Examples of possible field tape conditions which may be encountered are missing time samples, timing word errors, and different station start times. Although the LXMERG software is designed to cover these situations, it is impossible to check out all possible data configurations until actual field data is available. Also, the multiple station programming effort, LXMULT, will be influenced by results obtained from processing multiple station data, since event analysis should point out different network techniques which may enhance seismic signals at the network level.

SECTION VI
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6. J. P. Burg, "A New Analysis Technique For Time Series Data," Presented at the NATO Advanced Study Institute on Signal Processing with Emphasis on Underwater Acoustics.

7. Haskell, N., 1953, The dispersion of surface waves on multilayered solid media: Bull. Seis. Soc. Am., v. 43, p. 17-34.

8. Gilbert, F., and Laster, S., 1962a, Experimental investigation of PL modes in a single layer: Bull. Seis. Soc. Am., v. 52, p. 59-66.

APPENDIX A

LPE LIBRARY TAPE FORMAT

LX TAPE FORMAT

LOAD POINT
VOL-SERIAL HEADER RECORD (80 BYTES)
HEADER LABEL (80 BYTES)
EOF (TAPE MARK)
DATA RECORD #1 (2952 BYTES)
DATA RECORD #2 (2952 BYTES)
.
.
.
.
DATA RECORD #NREC (2952 BYTES)
EOF (TAPE MARK)
TRAILER LABEL (80 BYTES)
EOF (TAPE MARK)
EOF (TAPE MARK)

VOL - SERIAL HEADER

BYTES 0-3	HEADER IDENTIFIER	'VOLI'
BYTES 4-9	VOL - SERIAL	e.g., 'T00013'
BYTE 10	SECURITY INDICATOR	'1'
BYTES 11-79	RESERVED FOR EXPANSION	'b...b'

TOTAL LENGTH IS 80 BYTES - ALL DATA IS ALPHANUMERIC

TRAILER LABEL

BYTES 0-3	IDENTIFIER	'EOF1'
BYTES 4-28	RESERVED	'bb....b'
BYTES 29-34	VOL - SERIAL (NEXT TAPE)	e.g., 'T00057'
BYTES 35-79	RESERVED	'b.....b'

TOTAL LENGTH IS 80 BYTES

HEADER LABEL

BYTES	0-3	IDENTIFER	'HDR1'
BYTES	4-14	TAPE TYPE	'LOWbRATEbb$\frac{V}{D}$'
BYTES	15-20	LOCATION	'WAPSbb'
BYTES	21-26	VOL - SERIAL (THIS TAPE)	e.g., 'T00056'
BYTES	27-28	RESERVED	'bb'
BYTES	29-34	VOL - SERIAL (PREVIOUS TAPE)	e.g., 'T00055'
BYTES	35-36	LOCATION CODE	'02'
BYTES	37-38	TAPE TYPE CODE	'14'
BYTES	39-40	TAPE FORMAT VERSION	'01'
BYTES	41-46	DATE = 'bYRDAY'	e.g., 'b70181'
BYTES	47-52	RECYCLE DATE	'b99365'
BYTE	53	RETENTION CODE	'1'
BYTES	54-59	DATE = 'bYRDAY'	SAME AS BYTES 41-46
BYTES	60-65	PROCESSING SYSTEM	'IISPSb'
BYTES	66-67	RECORD LENGTH IN BYTES	2952
BYTES	68-69	SAMPLE RATE (20 = 2.0)	20
BYTES	70-71	STATION CODE FOR STATION 13	11
BYTES	72-73	STATION CODE FOR STATION 14	15
BYTES	74-75	STATION CODE FOR STATION 15	19
BYTES	76-77	CONSECUTIVE TAPE NUMBER	e.g.2
BYTES	78-79	RESERVED	'bb'

RECORD LENGTH IS 80 BYTES -

ALL DATA IS ALPHANUMERIC EXCEPT BYTES 66-77

DATA RECORD FORMAT

'LX'	BYTES 0 - 1
STATION LOG, 0 = GOOD SITE 1 = NO DATA OR BAD	BYTES 2 - 3
DAY = YRDAY (70121) 70 = BYTES 4, 5 121 = BYTES 6, 7	BYTES 4 - 7
TIME = SECS (84103) 84 = BYTES 8, 9 103 = BYTES 10, 11	BYTES 8 - 11
DATA FRAME #1	BYTES 12 - 109
DATA FRAME #2	BYTES 110 - 207
. . . .	BYTES 208...2755
DATA FRAME #29	BYTES 2756 - 2853
DATA FRAME #30	BYTES 2854 - 2951

TOTAL RECORD LENGTH = 2952 BYTES
FRAME LENGTH = 98 BYTES

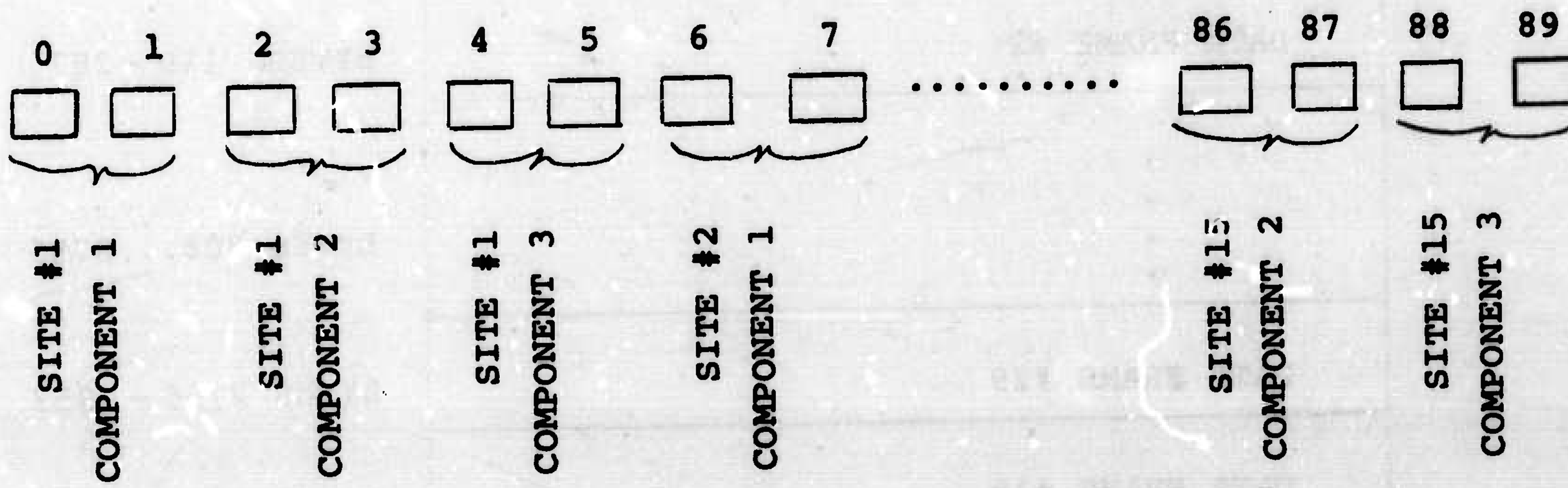
ALL DATA IS HALFWORDS

DATA FRAME FORMAT

LENGTH		POSITION
90 BYTES	DATA - RAW	0-89
8 BYTES	FLAGS .	90-97

RAW LONG PERIOD DATA (90 BYTES 0-89)

FRAME BYTE



Note: 2 BYTES/SAMPLE POINT RECORDED AS INTEGER HALFWORD DATA

BYTES 90-95 RESERVED

BYTES 96-97 MULTIPLEX ERROR COUNTER

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13. ABSTRACT

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